Efficacy and mechanisms of hydrotherapy in rheumatoid arthritis

Hall, Jane

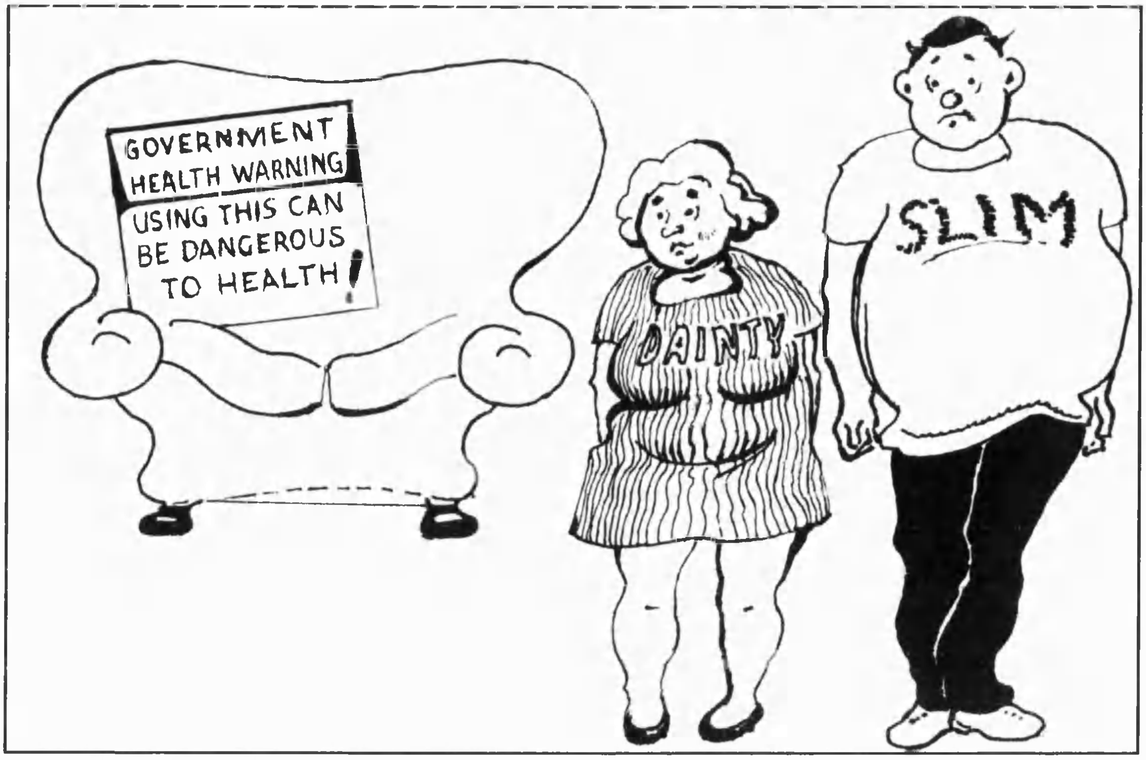
Award date:
2002

Awarding institution:
University of Bath

EFFICACY AND MECHANISMS OF HYDROTHERAPY IN RHEUMATOID ARTHRITIS

Submitted by Jane Hall
for the degree of PhD
of the University of Bath
2002.

Jane Hall



Adapted from: Buckley J, Holmes J and Mapp G. (2000). *Exercise on Prescription: Cardiovascular Activity for Health.* Oxford: Butterworth-Heinemann.

"The weakest and oldest among us can become some kind of athlete but only the strongest can survive as spectators, only the hardiest can withstand the perils of inertia, inactivity and immobility" Bland and Cooper,1984.

"Those who do not make time for exercise will eventually have to make time for illness" The Earl of Derby (1863).

ACKNOWLEDGEMENTS

First and foremost I would like to thank Professor Gerard Garbutt for supervising the latter half of my PhD. His good humour, knowledge and enthusiasm have made the last few years fun and I am grateful he took me on at a time when I could not have appeared a very hopeful prospect. I would also like to thank Professor David Blake for all his help and in particular for oiling the University and hospital wheels to enable me to continue after my "career break".

Peter Maddison, Professor Suzanne Skevington and Dr Paul O'Hare inspired me to pursue a PhD and I am grateful for their encouragement. Peter Maddison and Suzanne Skevington closely supervised the study presented in Chapter 2 and I would especially like to thank Suzy for the hours she spent with me during the data analysis period. Paul O'Hare was instrumental in setting the scene for the work detailed in Chapter 3. He also co-opted Professor Ian Macdonald, University of Nottingham Medical School, and I thank Ian for introducing me to the theory and practice of exercise testing.

Many thanks to Professor Francis Ring and Dr Bill Clarke who commented on earlier drafts of my thesis. Francis has consistently encouraged me to complete my PhD and has always come up with numerous and novel solutions to any problem posed.

Grateful thanks are extended to Fiona Phillips, Rebecca Cox and John Porter who carried out the physiotherapy treatments detailed in Chapter 4 and to Alison White and Ruth Clevely for poolside support; and to Trish Myers for secretarial and administrative support. The help, support and friendship from the physiotherapy and portering staff at the Royal National hospital of Rheumatic Diseases is gratefully acknowledged. Sally Jones and Julian Sims in the School of Social Sciences, Bath University provided computing support for which I thank them.

Special Acknowledgement

Kate Chapman set up the administrative systems for the study detailed in Chapter 4 and recruited the first 34 patients. For this I owe her a huge debt of gratitude and thank her for teaching me methods of study organisation which have made data collection, analysis and report preparation relatively painless.

I would like to thank Hazel Gimblett and Shirley Yard, Respiratory Physiology, Royal United Hospital, for constantly meeting my requests for help with the gas analysers during the time I was collecting data for the studies presented in Chapters 5 and 6. Thank you to the 2 Peters in Medical Physics, Royal United Hospital: Peter Dicken and Peter Laidler for their time, patience, generosity and friendshp. Grateful thanks to the following people who acted as laboratory assistants during the data collection periods in the Aquaciser lab: Audrey Ayling, Ian Bezodis, Michael Collier, Colin Delpaul, Hazel Gimblett, Owen Lewis, Val Russell, Jonathan Scott and especially to Linda Jefferson who helped me with equipment calibration. I gratefully acknowledge the friendship and support from the Physiotherapy Department at the Royal United Hospital, especially from Molly Paines, the cleaner, and Penny Farrar, the receptionist who did everything possible to help me. Thank you to the Works Department for converting a couple of cupboards into a laboratory and especially to Arthur Feltham and Ian Wadsworth, for their cheerful and lively help with the water treadmill maintenance and anything else I needed. Their knowledge of the Royal United Hospital site and its contents was invaluable when I was equipping the Aquaciser laboratory ! Statistical support for the treadmill studies was provided by Paul Christie, Bath University, Gordon Taylor, Research and Development Support Unit, Royal United Hospital and Paul Armstrong, University of East London. I greatly appreciate their help and thank them for stimulating my interest in statistics. Finally, I gratefully acknowledge all the subjects and patients who participated in the studies and made it all worthwhile.

Thank you to the South and West Research and Development Directorate for providing a research bursary and to the Royal National Hospital for Rheumatic Diseases, for funding the study detailed in Chapter 6. I am grateful to Ferno UK for providing the water treadmill and to PK Morgan for lending gas analysers.

Thank you to my friends Brian Walton and Pat McCarthy for providing first class computing support at home and to Frome Library for obtaining any article I requested. Also thanks to Peter Morgan for adapting and drawing the cartoon featured on page 2. Finally thanks to my friends and family who had to put up with me while I battled with my intellect and health.

ABSTRACT

Hydrotherapy for patients with rheumatoid arthritis (RA) is considered beneficial but the evidence base is weak. This thesis evaluates the efficacy of hydrotherapy with respect to its components : warm water immersion and exercise, and examines its potential as a cardiorespiratory stimulus.

A randomised clinical trial with 139 patients with RA showed that the exercise component of hydrotherapy was of central importance to the therapeutic effect. Given the physical properties of the water the effects may have been mediated by an increase in aerobic capacity. Therefore, an incremental walking test in water was developed and tested, firstly in normal subjects and secondly in patients with RA. The relationships between heart rate (HR) and ratings of perceived exertion (RPE) with oxygen consumption ($\dot{V}O_2$) differed as a result of water temperature and conditioning status. This means that the use of land-based HR or RPE values are inaccurate for exercise prescription in water. Results showed that land-based HR and RPE values would need to be increased by 9 beats·min^{-1} or 1-2 points on the 6-20 RPE scale respectively to achieve similar metabolic loads in water. Both normal subjects and patients with RA demonstrated an aerobic stimulus which was dependent on the speed of walking and conditioning status. The patients with RA in the treadmill study were younger and had a shorter disease duration than those in the clinical trial and it was speculated that improvements, resulting from hydrotherapy, may not have been mediated through increases in aerobic capacity. Based upon the experimental work in this thesis a plan for future research leading to a randomised clinical trial to establish the efficacy of hydrotherapy in improving aerobic capacity is presented.

CONTENTS

FIGURES.

TABLES

APPENDICES

ABBREVIATIONS

Arthritis Impact Measurement Scale (AIMS)

Blood pressure (BP)

Carbon dioxide production ($\dot{V}CO_2$)

Cardiac output ($\dot{Q}$)

C-reactive protein (CRP)

Health Assessment Questionnaire (HAQ)

Hydrotherapy (H)

Immersion (IMM)

Land exercise (LE)

Land relaxation (LR)

Maximal oxygen consumption ($\dot{V}O_{2\,max}$)

Oxygen consumption ($\dot{V}O_2$)

Rheumatoid arthritis (RA)

Stride frequency / cadence (S_f)

Stroke volume (SV)

Ventilation ($\dot{V}_E$)

Visual analogue scale (VAS)

Vital capacity (VC)

CHAPTER 1

RHEUMATOID ARTHRITIS AND EXERCISE

1.1. INTRODUCTION

Patients with rheumatoid arthritis (RA) experience swollen painful joints, disturbed joint motion and muscle weakness, resulting in disability. Many treatments are available to alleviate the symptoms. Hydrotherapy, under various guises, has been utilized for its healing properties even before Hippocrates recommended it for the relief of rheumatism, paralysis and fever. Today, the term hydrotherapy refers to exercise in warm water as prescribed and supervised by a physiotherapist. Prior to the 1st World War immersion *per se* was practiced for its therapeutic benefits. During the Roman era bathing in water of various temperatures was an important cultural and medical pursuit which resulted in the building of luxurious spa complexes for conquering armies recuperation. Whilst this scale of bathing diminished with the fall of the Roman empire, the use of water as a healing agent ebbed and flowed throughout the ages and it experienced a massive revival in the 18th century. The spa in Bath, built by the Romans over the site of a natural hot spring continues to yield 275,000 gallons daily. It became a haven for the sick and the rich in search of the "cure". Records from this period show that patients relaxed in the spa water for hours at a time and the physicians at the "Mineral Water Hospital"

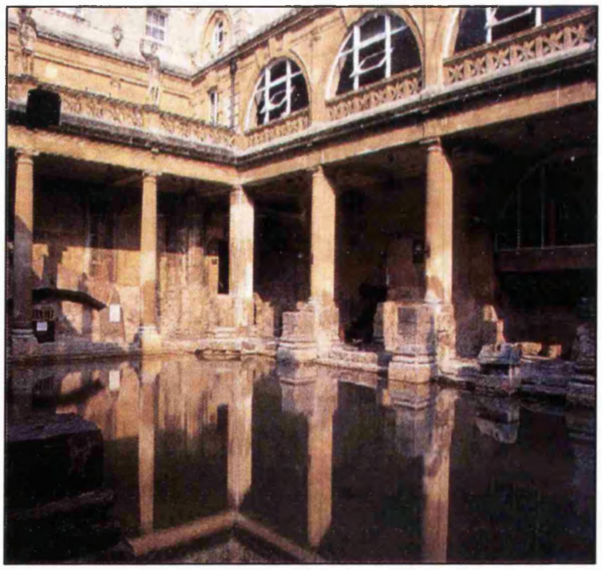


Figure 1.1 – The Roman Baths at Bath

(now the Royal National Hospital for Rheumatic Diseases) documented many successes. For example, many patients, suffering from lead poisoning (sustained from cider drinking !) benefited from the diuresis which improved the excretion of lead. This was confirmed in a recent study (Heywood et al., 1986). Immersion *per se* would appear to have therapeutic benefits as suggested by historical record.

The other component of contemporary hydrotherapy is exercise which is also associated with health related benefits (Kell et al., 2001; Wannamethee and Shaper, 2001; Pollock et al, 1998). It is therefore logical to assume that the net effect of combining the two will be greater than either used separately. However, the evidence base for hydrotherapy is sparse. Practice is informed via assumptions from exercise and thermal physiology studies, and more recently, from research into head-out water immersion. Immersion has become popular with space scientists as a model for weightlessness and with physiologists as a medium for studying volume homeostasis. Given the current climate of accountability, the lack of scientific foundation for hydrotherapy is derisory and well conducted studies, examining its components is overdue.

The aims of this thesis are to:

1) examine the hypothesis that hydrotherapy would confer significantly more therapeutic benefit than either immersion or exercise.
2) investigate the possible mechanisms which mediate any therapeutic effect.

Chapter 4 shows that the first aim was achieved via a randomized controlled trial using patients with RA, because hydrotherapy is universally accepted as being of most benefit to these patients. The mechanisms which mediate therapeutic benefit are likely to be multifactorial but given the increasing use of hydrotherapy as an aerobic training tool and the equivocal nature of the literature supporting this claim it is timely and relevant to examine this area. Furthermore, there is little to guide physiotherapists on accurate exercise prescription in water, especially for deconditioned patients such as those with RA. For this reason, a graded, incremental exercise test in water was developed so that the cardiorespiratory responses could be characterized, firstly in normal subjects (Chapter 5) and then in patients with RA (Chapter 6). In this way relationships between heart rate (HR) oxygen consumption ($\dot{V}O_2$) and perceived exertion (RPE) could be identified and used as the basis of future exercise prescription. Chapter 7 discusses the role of enhanced aerobic capacity in terms of the therapeutic effects gained from hydrotherapy and recommends strategies for improving cardiovascular fitness in water in patients with RA. In this first chapter the nature of RA and its physiotherapeutic management, with particular emphasis on exercise is reviewed. Chapter 2 reviews the role of hydrotherapy for patients with RA, its evidence base and the physiology of immersion. Chapter 3 considers appropriate measurement tools for examining the efficacy of hydrotherapy in RA patients.

1.2. RHEUMATOID ARTHRITIS

1.2.1. Definition and Pathogenesis

RA is a chronic inflammatory, progressive and disabling disease of synovial tissue characterised by symmetric polyarthritis. Although arthritis is the most frequent and common manifestation, RA is a systemic disease affecting many systems. Despite recent advances in molecular biology the aetiology remains uncertain but appears to result from a combination of genetic susceptibility, hormonal factors and exposure to an environmental trigger (Ollier, Harrison and Symmons, 2001). The initiation of chronic inflammation is considered to be the result of antigen-stimulated T cells which infiltrate the synovial membrane of the joint. This leads to the formation of immune complexes which activates the complement system. Examination of the synovium reveals angiogenesis and hyperplasia which later develop into pannus. This highly organised connective tissue is composed of a variety of cell types which release proteinases which are capable of destroying almost all the matrix proteins in articular cartilage and bone. With the perpetuation of the aberrant immune response the pannus, a proliferating, vascularised inflammatory granulation tissue, relentlessly replaces the articular cartilage causing irreversible destruction of the joint. Understanding of the start, and continuation of this process is not fully understood. Chronicity may be the result of the persistence of foreign antigen, the development of self antigens, a defect in the host antigen responsiveness or a combination. The end stages of the disease are characterised by transformation of pannus into a relatively acellular fibrous tissue which results in fibrous ankylosis.

1.2.2. Clinical Features

Patients experience swollen, tender, stiff and painful joints which results in disrupted joint motion and functional limitations. Typically the small joints of the hands and feet are involved early in the course of RA, but virtually any synovial joint, including the weight-bearing joints may be affected. Early morning stiffness is characteristic of the disease and malaise and fatigue are common. As a result of the pain and altered joint biomechanics muscle strength is reduced which may enhance the effects of joint destruction through loss of stability. Other functional limitations and psychological manifestations, including depression, are common.

The clinical course of RA is variable and unpredictable and therefore the causes of functional limitation alter depending on the stage of the disease. For example during the peri-diagnostic stage and periods of acute exacerbation pain and joint effusion may be the primary causes of joint restriction. Later, capsular fibrosis, muscle atrophy and loss of flexibility, tendon rupture, ligamentous laxity or shortening and bony or fibrous ankylosis may be involved.

1.2.3. Epidemiology

In industrial nations the prevalence of RA ranges from 0.5-1.5% of the population. It occurs more frequently in women than men (2.5 to 1) suggesting hormonal factors in the aetiogenesis. Whilst the disease can occur at any age it is most common in those aged 40-70 years. Approximately 50% of patients will be disabled or unable to work within 10 years of diagnosis which has major economic consequences both for the patient and society (Yelin, Henke and Epstein,1987). Life expectancy in patients with RA is reduced by approximately 7 years in men and 3 in women. This is due mainly to infections, renal and respiratory disease and the disease progression itself. Predictors of mortality include stress, age, male sex, poor functional status and low educational attainment (Sangha, 2000). The presence of extra-articular features contributes substantially to the morbidity and mortality of RA.

1.2.4. Diagnosis and Prognosis

In the absence of a specific test for RA diagnosis is based on the American Rheumatism Association criteria. This includes periarticular morning stiffness lasting at least 1 hour, symmetric arthritis of 3 or more joints, positive rheumatoid factor and radiological damage of the hands or wrists (Arnett et al., 1987). The diagnosis of RA is made if 4 of the 7 criteria have been present of at least 6 consecutive weeks. Onset may be insidious, making diagnosis difficult and time may have to elapse to allow the development of the characteristic features (Kim and Weisman, 2000). The spectrum of disease severity is broad and one of the challenges is to predict the course in the early stages. In some cases the disease is self limiting (approximately 40% of cases) but in the majority it is characterised by periods of remission and exacerbation for which criteria have been developed (Pinnals et al., 1981). Knowing early in the course of the disease which patients are going to experience a mild or severe course is essential for providing the best treatment. At present there is no single indicator for this, rather a number of risk factors, including sex, early development of joint erosions, presence of rheumatoid factor, presence of extra-articular features and early disability predict a more severe course (Lee and Weinblatt, 2001).

1.2.5. Treatment of rheumatoid arthritis

The management of RA patients involves a variety of interventions prescribed by the multidisciplinary team and is long-term, given the chronic nature of the disease. Pharmacological treatment is the mainstay of treatment and is aimed at suppressing the inflammatory response. Its success is measured by the degree of functional disability and the presence of radiographic erosions.

In the past decade the drug management of RA has changed significantly as the development of novel therapies has arisen from greater understanding of the inflammatory pathways and as it became apparent that the pyramidal approach was ineffective in preventing progressive disability and the consequent socio-economic problems. The conservatism of the therapeutic pyramid whereby disease modifying anti-rheumatic drugs (DMARDs) were introduced only when clear evidence of joint erosions were seen has been superceded by a more aggressive (and potentially toxic) regime. Presently, patients considered at risk of developing persistent and progressive disease are introduced to this new regime within weeks of diagnosis (Lee and Weinblatt, 2001). The action of DMARDs is incompletely understood but they reduce markers of inflammation such as erythrocyte sedimentation rate and reduce the number of swollen joints as well as improving functional status. However future research is required to monitor their long-term effects, especially side-effects and toxicity and to establish optimal dosage and treatment duration.

Non-steroidal anti-inflammatories (NSAIDs) continue to provide immediate pain relief and are prescribed routinely for patients with RA. Whilst analgesic, their long-term use is associated with many side effects including gastric ulceration and perforation, renal toxicity, central nervous disturbance (eg, headache, dizziness) and haematological abnormalities (eg, neutropenia, anaemia). The recent introduction of selective COX-2 inhibitors which provide anti-inflammatory and pain relieving effects without gastric or haematological upset has been accepted with enthusiasm by patients with RA (Førre et al., 2000).

The paradigm shift from watchful waiting to aggressive early intervention within the last decade appears to be changing the clinical picture of RA (Pincus et al., 2001). The natural history of the disease has been one where, despite treatment, measures of inflammatory activity have improved or remained unchanged whilst radiological evidence of joint damage has shown relentless progression (Callahan et al., 1997). However, it will be another decade before research will show whether the new drugs and regimes live up to their early promise.

The limitations of current medication sustain the use of intra-articular injections for recalcitrant joints and in surgical terms, joint replacement therapy. Despite the advances in pharmacological agents and technology physiotherapy management remains a fundamental element in the treatment of RA.

1.2.6. Physiotherapy Management

The goals of physiotherapy management in RA are two-fold: to maintain the patient's independence and facilitate the best quality of life within the restrictions imposed by the disease (Gerber, 1989). Meeting these objectives requires long-term and ongoing assessment of the patient's physical condition in the light of social, psychological, work and environmental factors.

The principles of physiotherapy are firmly established:

a) relief of pain

b) prevention/correction of deformity

c) maintenance and restoration of joint range of movement

d) maintenance and improvement of muscle strength

e) maintenance of optimum function (Ward and Tidswell,1984).

The techniques are many and varied (Sutej and Hadler, 1991) and choice depends more on the patient's condition, the facilities available and the expertise of the therapist than the evidence base, which is limited. Given the relationships between disability and pain and psychological factors (eg, helplessness) a biopsychosocial approach to treatment is recommended (Schoenfeld-Smith et al., 1996). Patient education should form a vital component of the therapy management and the content, style of presentation and effectiveness in terms of patient knowledge, skills, beliefs and attitudes which impact on health status and quality of life continues to be investigated (Taal et al., 1996).

1.3. EXERCISE IN RHEUMATOID ARTHRITIS

Traditionally exercise has been viewed as detrimental to patients with RA. Fears regarding accelerated joint damage fuelled the physician's suspicions and patients, suffering from great pain and fatigue, did little to challenge this view. The little exercise that was permitted tended to be static and concentrated on non-aerobic isometric muscle strengthening and range of movement exercises. However, the last decade has seen major attitude changes towards exercise as a result of research which suggests that exercise does not exacerbate or hasten joint damage. Furthermore, increased knowledge regarding the benefits of regular moderate exercise have helped to change anachronistic views held by the professionals. Added to this patients have been given greater empowerment to challenge their treatment by government policy and global access to the information highway. Contemporary practice encourages patients to exercise although long term support for this appears inadequate and the nature of comprehensive exercise programmes uncertain. Future research needs to examine best methods of service delivery in a population with long term and changing clinical exercise needs.

The major goal of therapeutic exercise in patients with RA is to improve functional capacity by strengthening muscles, increasing joint mobility and aerobic endurance without exacerbating joint symptoms. The emphasis on exercise shifts during the different stages of the disease. During episodes of acute joint inflammation rest therapy continues to be advocated (Alexander et al., 1983; Smith and Polley., 1978; Partridge and Duthie, 1963) and exercise is limited to preventing the deleterious effects of bed rest and minimising joint deformity. Therefore exercise during periods of increased disease activity is limited to non-aerobic static exercise. In their review on rest therapy for RA, Smith and Polley (1978) argue that pathophysiologic, biophysical and clinical evidence supports the thesis that "rest of inflamed joints and tissues is beneficial and that use of inflamed parts is harmful". Furthermore, Blake et al. (1989) showed that exercise of inflamed joints provides a suitable environment for the promotion of hypoxic-reperfusion injury which perpetuates synovitis. However, a recent and daring randomised controlled study showed that a short-term intensive exercise programme (ie, HR was maintained at 60% of age predicted maximum) in hospitalised active RA patients was not deleterious but increased muscle strength and physical function (van den Ende et al., 2000). The complex and incompletely understood relationship between disease activity and joint damage makes speculation about the long-term effects of this study difficult. However, confirmation of these results could have implications for the future treatment of active RA. During periods of remission when the joints are minimally active, the emphasis shifts towards a progressive exercise programme, tailored to the individual, and aimed at decreasing disability and improving physical conditioning (Semble et al., 1990; Smith and Polley, 1978).

Patients with RA are physically deconditioned by periods of inactivity (during acute phases) and the adoption of a sedentary lifestyle. Neuberger and colleagues (1994) reported that, in the 7 days preceding their study, 43% of the sample had not participated in range of motion exercises and 76% had not performed strengthening exercises. Physical deconditioning is considered a secondary rather than a primary disease process (Piha and Voipio-Pulkki, 1993). Interestingly, 50% of RA deaths are due to cardiovascular disease (Wolfe et al., 1994) which has been partly explained by higher diastolic blood pressure, possibly induced by NSAIDs (McEntegart et al., 2001).

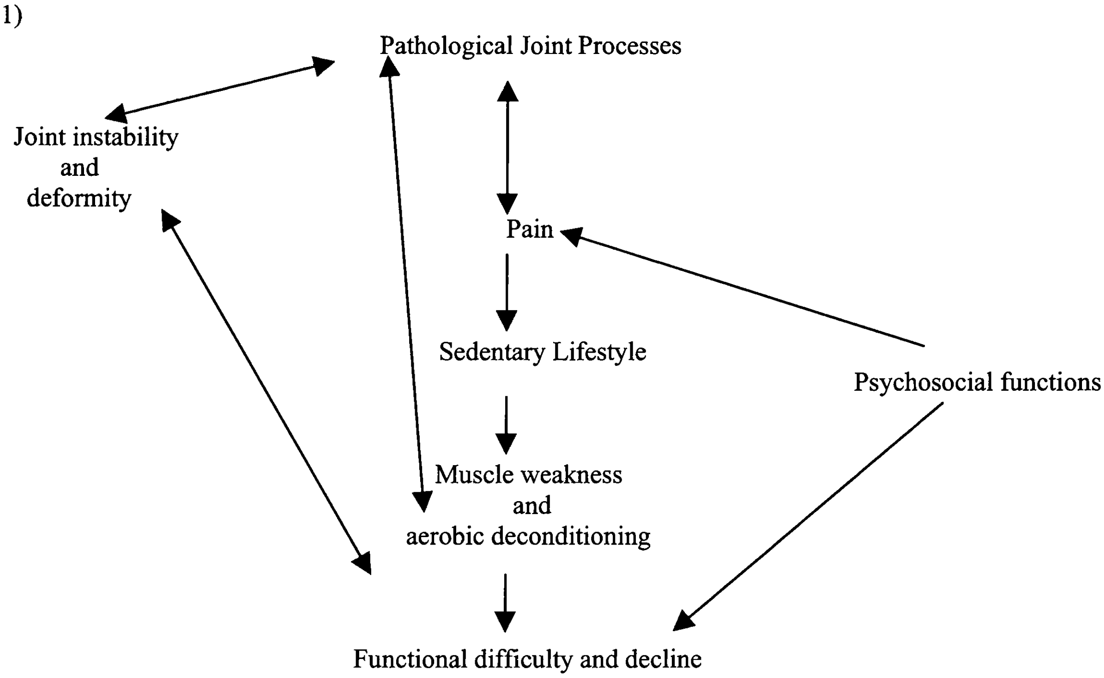
Importantly, inactivity is an independent risk factor for cardiovascular disease with Komatireddy et al. (1997) reporting that 2 patients within the sample of 49 demonstrated abnormal stress tests (as a result of dormant coronary artery disease) during a symptom limited treadmill test. Therefore, regular moderate exercise should be promoted to the RA community, not only for the possible musculoskeletal benefits but also for the known cardiovascular advantages.

The deconditioning is characterized by reduced cardiorespiratory function, muscle atrophy and weakness, decreased flexibility and loss of agility (Hakkinen et al., 1995 and 1999a; Çimen et al., 2000; Ekdahl and Broman, 1992; Minor et al., 1988; Hsieh et al, 2000; Ekdahl and Broman, 1992). The consensus demonstrates that patients with RA have a 25-30 % reduction in maximal oxygen consumption ($\dot{V}O_{2\,max}$) compared to healthy age and sex matched controls. For example, Ekdahl and Broman (1992) demonstrated that $\dot{V}O_{2\,max}$ for 23 females with RA, aged between 23-54, was 22.3 (SD ±6.8) $ml \cdot kg^{-1} \cdot min^{-1}$ and 31.7 (SD±12.1) $ml \cdot kg^{-1} \cdot min^{-1}$ for healthy control women. This reduced aerobic capacity has been shown to occur within 4 years of the diagnosis of RA (Beals et al., 1985). Further evidence of deconditioning comes from the work of Piha and Voipio-Pulkki (1993) who showed that RA females had a significantly higher HR than healthy controls (69 versus 63 $beats \cdot min^{-1}$). In addition to low cardiorespiratory fitness patients with RA have reduced muscle strength. This occurs early in the disease with Häkkinen and colleagues (1999a) showing that knee extension strength was 46%, grip strength 31% and trunk extension strength 14% lower than controls in a sample of 20 RA females with a mean disease duration of 11 months. Similar results have been noted by others (Ekdahl and Broman, 1992; Ekblom et al., 1974; Beals et al., 1985;

Ekdahl et al.,1989). The causes of muscle atrophy have yet to be elucidated but may be related to disuse/misuse, secondary to pain avoidance, joint deformity and arthrogenous muscle inhibition, drug-induced myopathy, myositis, vasculitis, peripheral neuropathy and systemic illness (Harris, 1989). Joint range of movement also shows deficits. Active shoulder flexion showed a 20% reduction in 42 female RA patients aged 50 (±11.3) with a disease duration of 8 (SD ± 8) years (Minor and Hewett, 1995).

The effects of joint pathology and physical deconditioning affects, in part, patients functional capacity (Figure 1.2). Received wisdom suggests that improving physical fitness will positively influence functional capacity and this is one of the major goals of exercise in RA. The next section will critically review the evidence to support the theory that exercise can result in beneficial changes to physical, clinical and psychological status in RA patients.

Figure 1.2 - The cycle of joint pathology, pain, inactivity, and functional decline (Adapted from: Ettinger, 2001)



1.3.1. Exercise intervention in rheumatoid arthritis

A recently conducted systematic review of exercise in RA concluded that dynamic exercise has a positive effect on aerobic capacity, muscle strength and joint mobility (van den Ende et al., 1998). As a caveat it should be noted that research into the effects of exercise in RA is almost entirely limited to patients with mild disability and categorised as either Functional Class I or II after the American College of Rheumatology global functional status criteria (Hochberg et al., 1992), thus limiting external validity (Appendix 1.1). Whilst dynamic exercise has been shown to improve physiological and physical variables its effect on functional ability is less certain but this may be a consequence of inadequate measurement tools. The self-report questionnaires used in the 6 studies which met the review's inclusion criteria were limited to areas of health status relating to the performance of daily activities. Health status constructs which might be positively influenced by exercise such as activity level, fatigue, endurance and work capacity are not included in the commonly used questionnaires and suggest the need for the development of instruments which cover these dimensions. Furthermore, the majority of patients participating in dynamic exercise trials was limited to those with non-active disease and mild disability who would be expected to achieve a low disability score. Detecting slight functional change challenges the sensitivity of the instrument and suggests that either more sensitive measures are used or other methods of functional ability, such as timed performance tasks are developed to elucidate the effect of exercise on functional ability. Furthermore, it also been suggested that the lack of functional ability increase following exercise interventions may result from an inability to integrate the new skills into activities of daily living (Stenstrom, 1994a).

Importantly, the review showed no detrimental effects of short term exercise (12 weeks) on disease activity and therefore states that there is no evidence to prevent RA patients from exercising at levels of 60% of $\dot{V}O_{2\,max}$ or above. Less clear is the effect of exercise on radiological progression. The results of one two-year study demonstrated no change in joint radiology between the exercise groups but baseline values differed and sample sizes were small (Hansen et al.,1993). Similarly, Hakkinen et al., (1998), reported no deleterious effects on joint erosions of 6 months of supervised resistance training with a 3.5 year follow-up. Reports from non–randomised studies which were not included in the review also suggest that exercise, whether of high or low intensity, and the frequency of exercise do not negatively influence radiological progression (Stenstrom, 1994b and 1991; Nordemar et al., 1981). However, methodological shortcomings limit the impact of these findings and given the drug paradigm shift since publication of the studies there is an even greater need for further research to establish the effects of dynamic exercise on radiological progression.

The review did not address the effects of exercise on psychological function. Given the vast amount of literature devoted to this area within the context of RA and the beneficial effects of dynamic exercise on psychological status reported by numerous reviews this represents a serious omission (Weyerer and Kupfer, 1994; Byrne and Byrne, 1993; Plante and Rodin, 1990). However, it should be recognised, that of the 6 studies included in the review only one included a measure of psychological function (Minor et al., 1989). Despite this Stenstrom (1994a) reports positive effects on the qualitative disease aspects of RA such as social, emotional, cognitive and behavioural factors in her review of therapeutic exercise in RA.

The review by van den Ende and colleagues (1998) was limited to randomised trials which met strict inclusion criteria including blinding of outcome assessor, description of treatment allocation, similarity of groups at baseline and presentation of point estimates and measures of variability and were published up to 1997. Since that time other studies on the effects of exercise in RA have been published and are worthy of mention. A recent randomised controlled trial on the effects of a 12 month home exercise programme in patients with RA on low-dose oral corticosteroids met most of the stringent criteria set by Verhagen et al., (2001) and so the results may be viewed with some confidence (Westby et al., 2000). Despite the disparity between calculated sample size and actual recruitment (50% difference) and the use of multiple t-tests the exercising patients improved their functional ability. Furthermore, activity levels as measured by the Caltrac, a motion sensor device that monitors energy expenditure, increased over the study period. Despite the recent evidence that suggests this accelerometer overestimates energy expenditure in older women, a 200 kcal increase in energy expenditure remains within the daily 100-300 kcal increase recommended by the American College of Sports Medicine (ACSM) for significant health benefits (Fehling et al.,1999). It should be noted that the significance values would have become non-significant if a Bonferroni factor had been applied to correct for the vagaries of multiple testing. Nevertheless this study supports the growing body of evidence for the use of exercise in chronic RA and it also showed no adverse effects in terms of disease activity as measured by joint count and erythrocyte sedimentation rate. This study was home-based, and the frequency and methods of supervision, whilst unclear suggest minimal contact once the trial had begun. Despite the use of exercise logs which suggested a high degree of compliance the outcome measures may have improved more if greater contact had been established. So, in terms of exercise benefits not only must the content, intensity, duration and frequency of the exercise be considered but also the method of service delivery. Three further studies confirm the evidence for the safe and effective use of resistive exercise in non-active RA (Hakkinen et al., 1999b; McKeeken et al., 1999; Komatireddy et al., 1997).

The literature supports the use of dynamic exercise therapy in patients with quiescent RA. Whilst one study suggests it is safe in patients with active disease, confirmation of these findings is required. Nonetheless, questions remain about the efficacy and long-term safety of different types of exercise interventions as well as issues of exercise adherence and optimal service delivery. One mode of exercise favoured by patients with RA is hydrotherapy.

CHAPTER 2

HYDROTHERAPY AND IMMERSION PHYSIOLOGY

2.1. INTRODUCTION

Hydrotherapy is a popular treatment for patients with RA because the warmth of the water soothes their pain and the buoyancy reduces the compressive forces through their joints. It is important to define the term hydrotherapy as it can encompass a wide range of therapies in water. In the UK, hydrotherapy is defined as a "pool therapy programme specifically designed for an individual to improve neuromuscular skeletal function conducted and supervised by appropriately qualified personnel, ideally in a purpose built hydrotherapy pool" (Goldby and Scott, 1993). In Europe hydrotherapy, also known as balneotherapy, spa therapy or thallasotherapy depending on the mineral properties of the water, concentrates on a more passive approach of bathing and immersion. The mineral properties of the water and the spa experience are regarded as important factors in any therapeutic benefit. For these reasons research conducted in spa resorts has been excluded from this review on hydrotherapy. Exercise in warm water is currently experiencing the popularity accorded to the aerobics boom of the 1970/80s and numerous modes of exercise have been developed to appeal to different groups. For

Figure 2.1 – Supervised hydrotherapy

example, aquarobics take place in leisure and hospital pools. Walking and running activities in shallow and deep water are increasingly employed by athletes and others as a fitness training tool, especially during periods of injury when full load-bearing is prohibited. These

Figure 2.2 - Aquarobics

activities may be of benefit to patients with RA, but need to be fully evaluated for suitable content and safety. Furthermore it should be recognised that the physiological and perhaps therapeutic effects will differ depending on the pool setting as this influences the water temperature. Leisure pools typically operate at much lower temperatures than therapeutic facilities (28°C versus 35°C) and this may have implications for patient exercise behaviour. To keep warm in low water temperatures higher exercise intensities are demanded and perception of pain relief may be less. So patients with RA may view leisure pool/community activities with less enthusiasm than therapeutic pools. This often means that, once a patient has completed a hydrotherapy course in the hospital environment, continuation is partly dependent upon the patient's tolerance of cool water. At present no data have been found relating the continuation of exercise in water following a hydrotherapy course, or the barriers to compliance.

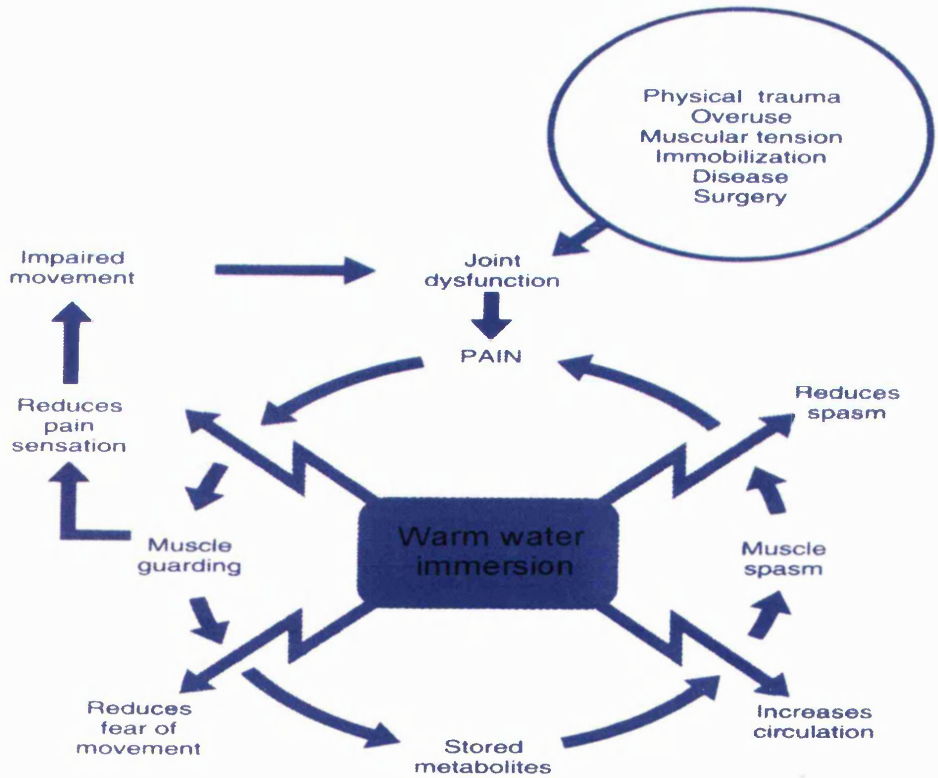
2.1.1. Claims and Rationale

Many claims have been made on behalf of hydrotherapy and standard textbooks maintain that this treatment provides a holistic medium catering to the physical, psychological and social well-being of the healthy and infirm (Campion, 1990; Davis and Harrison, 1988; Skinner and Thompson, 1983). Campion (1990) lists the benefits of hydrotherapy as: relief of pain, reduction of oedema, reduction of muscle spasm, promotion of muscle and general relaxation, increase in joint range of movement, increase in muscle strength, improvement in functional ability, improvement in aerobic fitness and enhancement of well-being - attributed to the satisfaction of performing movements which may be impossible on dry land.

The rationale for such claims rests, largely on the physical properties of the water, although the psychosocial benefits of group treatment by an empathetic therapist should not be ignored. The warmth of the water is considered of major benefit in alleviating pain and muscle spasm and promoting relaxation, although the mechanisms by which this may occur have yet to be explored in hydrotherapy. However, superficial heating and an increase in core body temperature are known to affect metabolic activity, haemodynamic function, neural response and skeletal muscle activity (Palastanga, 1994). Vasodilation mediated by the axon reflex mechanism may increase circulation and this can aid in the dispersal of algogenic chemicals, thus reducing nociception (Palastanga, 1994). Furthermore, activation of large diameter myelinated fibres via thermal sensation and mechanoreceptor stimulation from exercise fulfils the criteria for "closing" the gate to predominantly small nociceptive impulses, which may contribute to pain relief from hydrotherapy (Melzack and Wall, 1988). Finally, pain resulting from muscle spasm may be alleviated through reduced muscle spindle excitability as well as an increase in blood flow (Michlovitz, 1990).

The warmth of the water may also contribute to patients reporting that they can move more easily in water than on land. Joint viscosity may be reduced and collagen extensibility increased, hence stiffness is reduced and the point at which nociceptive stimulation results from stretching may occur further into the range, thereby allowing the patients to move more easily and with greater range of movement than on dry land (Gersten, 1955). Figure 2.3 illustrates the possible mechanisms whereby the warmth of the water may alleviate pain.

Figure 2.3 – The warmth of the water may alleviate pain. (Reproduced with permission from Bates and Hanson, 1996).



An enhanced ability to move may also be attributed to the buoyancy of water, which effectively reduces the weight through the body (Harrison and Bulstrode, 1987) and hence reduce the compressive forces taken through joints. Gunga and Kirsch (1989) noted increased vertebral column lengthening after a period of immersion and Dowzer et al., (1998a) recently observed reduced spinal shrinkage following deep water running compared to land running. This relative joint distraction may be of significant benefit in reducing pain and enhancing mobility in RA joints. The unloading as a result of buoyancy has been shown to induce almost complete bioelectrical silence and reduction in tone from the anti-gravity muscles and this may be a factor in pain relief and ease of movement (Sugajimo et al., 1996; Mitarai et al.,1972).

Further reasons for some of the claims made on behalf of hydrotherapy relate to the increased hydrostatic pressure on the body during water immersion. The physiological effects of immersion are reviewed on pages 48-58 in this chapter. Briefly, the increased hydrostatic pressure affects the Starling forces across the capillary such that oedema may be reduced which may have a positive influence on pain relief and ease of movement. Furthermore, the increased hydrostatic pressure dampens activity of the sympathetic nervous system (page 55). As the sympathetic nervous system is closely associated with central pain modulation (Wall and Melzack, 1994) and is considered to contribute to the maintenance of chronic pain, overall dampening of the system may be beneficial.

The resistance to movement from the viscosity and weight of the water, from the negative drag due to turbulence and from the upward force of buoyancy makes the hydrotherapy pool a suitable environment for muscle strengthening. These factors are manipulated by the therapist to achieve an appropriate individualised level of muscle activity. For example, adduction of the arm, when immersed to shoulder level, is considerably more demanding when floats are held in the hand than without. Because the resistance to movement increases, in part, as a log function of velocity, increasing the speed of movement increases the muscle force required (Becker, 1997). The shape and size of the moving object also increase the resistance to movement. Therefore, changing the length of the lever and its shape from streamlined to non-streamlined has significant implications for the muscle force required. Given adequate attention to the principles of muscle training it should be possible to strengthen muscles by a hydrotherapy programme. Furthermore, these frictional properties of water are considered responsible for the ability to improve aerobic capacity once a suitable conditioning programme has been completed.

2.1.2. The Evidence Base for Hydrotherapy

Despite its long history and continuing popularity, the evidence base for the efficacy of hydrotherapy in any disease/disorder, including RA is minimal. Good research methodology, as defined by Verhagen et al. (2001), may be more difficult in hydrotherapy for reasons of experimental design as it is not possible to blind the patient. Also, the longitudinal nature of such interventions may increase the potential for subject attrition. For these reasons and because the effect size is not known, achieving a large enough sample for meaningful statistical analysis is problematic. Furthermore, hydrotherapy studies may be potentially expensive in terms of staffing and plant running costs and protected pool time may be impossible given the popularity of hydrotherapy. However, a systematic review on balneotherapy for rheumatoid arthritis and osteoarthritis has recently been published which synthesises the findings from 10 randomised controlled trials, selected according to strict eligibility criteria (Verhagen et al., 2000). The review concludes that the scientific evidence for the efficacy of balneotherapy is weak because of the poor methodological quality of the studies and the omission of the most essential outcome measure for the patient (quality of life and pain). It goes on to state that the positive findings of most of the studies cannot be ignored and urges further research which avoids current flaws. This review included 6 studies conducted in European spa resorts, with the emphasis on passive bathing, and 2 in which the effects of hydrotherapy in hip osteoarthritis was examined. It is therefore clear that there is a dearth of research on the efficacy of hydrotherapy in RA as practiced in the UK and further highlights the need for a well conducted trial. Nonetheless, by taking a less stringent approach to the quality of the studies one is able to get an appreciation of the current state of knowledge with regard to hydrotherapy and RA.

As a result of a literature search, eight studies were identified through MEDLINE and Embase databases and reference lists of relevant published studies. Four of the studies were randomised controlled trials (Sandford-Smith, 1998; Rintala et al., 1996; Ahern et al., 1995; Minor et al., 1989), the rest were not, which limits their internal validity (Templeton et al., 1996; Stenstrom et al., 1991; Danneskiold-Samsoe, 1987; Dial and Windsor, 1985). The majority of the subjects had RA, although 1 study comprised 68 patients with lower limb osteoarthritis and 28 patients with RA (Minor et al., 1989). The average age of the patients in the 4 studies was 54 years and the majority were female with an average disease duration of 11 years, although the individual study standard deviations were large. No studies included very disabled patients (ie, Functional Class IV) and most were on disease remitting drugs. All studies were based in a hospital pool and the hydrotherapy sessions supervised by physiotherapists.

All the studies reported improvements in function following hydrotherapy but the methods of measurement were diverse and sometimes suspect with regard to issues of reliability and validity. Function has been measured by assessing changes in $\dot{V}O_2$, muscle strength, joint range of movement, self-report measures and the use of timed or scored tasks such as a walking test.

One randomized controlled trial reported no changes in $\dot{V}O_2$ after hydrotherapy (Rintala et al., 1996) and three studies reported gains in $\dot{V}O_2$ but the evidence is equivocal because of methodology defects (Sandford-Smith et al., 1998; Minor et al., 1989; Danneskiold-Samsoe, 1987). The study by Minor et al.(1989), in which 96 patients, of which 68 had lower limb osteoarthritis and 28 RA, were randomly allocated to one of 3 exercise conditions reported that the hydrotherapy group increased aerobic capacity by 20%. However, the method of data analysis does not allow separation of the patient groups making conclusions on the efficacy of hydrotherapy as a method of increasing aerobic capacity in RA impossible. Interestingly, the way in which the data are further pooled (the land and water exercise groups are subsumed into 1 aerobic group) suggests that equal gains in aerobic exercise occur, independent of environment. In a recent systematic review of exercise in RA van den Ende (1998) noted that those studies with the lowest methodological quality, of which Minor et al's study is one, reported greater increases in aerobic capacity than studies with better methodological approaches. In an uncontrolled study which considered muscle strength as the primary outcome measure 6 patients with RA improved $\dot{V}O_2$ by 11.7% (Danneskiold-Samsoe, 1987). However, the sample size was small, there was no control group and there was great variability of response which could have biased the results. Furthermore, Deveraux et al. (2002) reported that unblinded data collectors can introduce bias through differential encouragement during performance testing. Therefore, at present the evidence, whilst suggestive that hydrotherapy may improve aerobic capacity is inconclusive.

Given the accommodating resistance to movement as a result of velocity in water it is rational to assume that muscle strength may be increased when an appropriate training regime is used. Once again, the lack of good quality studies prevents incontrovertible conclusions being made, but the literature is suggestive that improvements in muscle strength do occur after hydrotherapy interventions. Despite the lack of a control group 8 patients with RA increased isometric and isokinetic quadriceps strength by 38% and 30% respectively following an 8 week (twice a week for 45 minutes) supervised hydrotherapy programme. When synthesising the magnitudes of muscle strength improvement in dynamic exercise studies in RA (approximate increase range from 0-35%) these gains represent the higher end of the spectrum, which is surprising given the short-term nature of the intervention. Together with the uncontrolled nature of the study this casts doubt on the reliability of these results, future research is required to examine the efficacy of hydrotherapy programmes in promoting muscle strength in patients with RA.

Given the importance of hydrotherapy in increasing range of movement reporting of such measures in the literature is surprisingly low. Nevertheless, Minor et al. (1989), reported a 7.2% increase in trunk flexibility using the sit-and-reach test in patients with OA and RA but the method of data pooling makes it impossible to estimate the effect in RA. Dial and Windsor (1985) reported a statistically significant increase in the active range of movement of various joints measured before and after a hydrotherapy intervention. However the clinical significance of these findings is dubious. In this study 12 patients with RA completed an 8-week (twice weekly) health education-water exercise programme and results of goniometric shoulder range of movement after treatment showed an improvement of 5.2°. Given the error associated with goniometry it is likely that this degree of change reflects measurement error rather than true change. In a randomised clinical trial Rintala et al. (1996), reported significant gains in a joint mobility index in the hydrotherapy group only but the clinical significance of the 0.5 change is not explained. Thus convincing evidence for range of movement/flexibility gain awaits further investigation. Therefore, the measurement of joint mobility will be included in the trial presented in this thesis.

Self-report measures of function and functional tasks have been used to assess the efficacy of hydrotherapy. There is little evidence to substantiate this method. One of the problems is the lack of disease specific reliable and valid assessment tools. Future studies should benefit from the continual development and refinement of such instruments. Only one study has reported physical function using a valid and reliable self-report questionnaire (Minor et al., 1989). This showed that patients increased their physical function by 24% after a pool programme, but as has been mentioned before, isolating the extent of improvement in patients with RA is not possible. In an uncontrolled study Stenstrom et al. (1991) reported the results of a series of functional tests, designed to test arm and hand function, lower limb function and balance, flexibility and endurance in patients with RA who participated in a long-term water exercise programme. At the end of the 4-year study period patients who had exercised regularly did not differ, in terms of function to a similar group of RA patients who had declined the opportunity to exercise. The authors suggested that an inability to integrate the new skills into activities of daily living, insensitive measures or study design may have been responsible for this disappointing result. Given similar findings in studies of dynamic exercise in RA in which physical capacity increases without a corresponding carry-over into functional ability it may be that patients have an inability to integrate the new skills into activities of daily living or the measures are insensitive. If this is the case it might be worth considering a more functional approach to RA rehabilitation and training patients, not only in gait re-education as is frequently done but also in patient targeted specific functional tasks, for example sit-to-stand.

A recurring theme in the literature on hydrotherapy, regardless of patient group and study design, is an enhancement of well-being. As hydrotherapy is often performed in groups this is attributed to the potential sociability of the treatment and the support offered by other patients as well as the close contact with empathetic therapists. In 2 studies the most beneficial aspects of the hydrotherapy intervention were cited as "fellowship and social support from others" (Dial and Windsor, 1985) and "increased sense of well-being" (Stenstrom, 1991). Improved psychological state has been measured more formally in Minor's study (1989) using the Arthritis Impact Measurement Scale (AIMS). This showed that anxiety and depression reduced significantly after hydrotherapy but returned to baseline values at 3 months follow-up. Once again the method of data handling makes estimates of the effect in RA patients impossible. Interestingly, improvement in psychological state occurred only in those patients engaged in aerobic exercise as compared to non-aerobic exercise which confirms previous reports on the benefits of improved fitness and the psyche (Weyerer and Kupfer, 1994; McAuley and Rudolph, 1995). Given the pervasive suggestion that hydrotherapy may improve psychological state future studies should measure specific aspects of this construct using valid and reliable instruments.

The ultimate aim of RA management is cessation or at least suppression of joint damage. Whilst the relationships between joint damage and disease activity are complex and unclear it is considered highly desirable to reduce the latter in an attempt to halt the former (Callahan et al., 1997). This scenario is thought to be beyond the realms of physical treatments, such as hydrotherapy, but measurement of disease activity and joint damage are important to assess for reasons of safety. Clearly, treatments which cause a significant increase in synovitis and haematological markers of inflammation would be viewed in the same light as exercise was in previous decades, and rejected. In terms of hydrotherapy disease activity markers have been limited to clinical and radiological measures, both however show no evidence of increase. Indeed the general trend would suggest that hydrotherapy could positively influence disease activity. Despite the uncertainty of diagnosis, ie, what percentage of the 40 patients had RA as opposed to OA, the aerobic aquatic group in Minor et al's study were the only group to demonstrate significant improvements in duration of morning stiffness, in the number of clinically active joints and grip strength at post-test. These changes, apart from the duration of morning stiffness were maintained at 3 and 9-month follow-up. The Ritchie index, a measure of joint tenderness, remained unchanged in either group in Stenstrom's (1991) long-term hydrotherapy study but the training group increased in grip strength whereas the control group deteriorated. Importantly, no significant differences between the groups was noted for radiological progression of joint erosions. Therefore, it would seem that short and long-term hydrotherapy programmes are not deleterious to disease activity on the basis of clinical and radiological evidence. At present no hydrotherapy study has reported on laboratory measures of disease activity such as erythrocyte sedimentation rate and C-reactive protein. Since both these measures correlate with disease activity and the development of erosions, it is a surprising omission which should be rectified in future studies (Persselin, 1991).

One of the most important indications for hydrotherapy is the relief of pain. Despite this, there is little evidence to suggest that hydrotherapy is efficacious in reducing pain although this may be due to the poor quality of existing studies. Some studies do report pain relief following hydrotherapy (Rintala et al., 1996; Dial and Windsor, 1985) but others do not (Stenstrom et al.,1991; Minor et al., 1989). These findings are disappointing and may testify to both inadequate measures of pain and the lack of sound research design.

The beneficial claims for hydrotherapy are many and diverse and patients with RA hold hydrotherapy in the highest esteem, as do their physiotherapists. At present there is little good scientific evidence to substantiate this although the studies presented here show promising results that demand further efforts. Therefore a randomised clinical trial of hydrotherapy using reliable and objective measures is required to determine the efficacy of hydrotherapy in RA.

2.1.3. Hydrotherapy = Immersion + Exercise

If hydrotherapy confers positive benefits, then understanding the mediating factors should enable the treatment to be optimised in individual patients. Indeed, searching for a rational explanation for the effects of hydrotherapy does not appear to be the prerogative of today's researchers. Sutherland, in 1764 attempted to understand the process by which James Crook of Long Acre benefited after 3 immersions: "from the rigidity and the pressure of the fluid, we may account for his pissing more than he drank". This highlights the diuresis which is one of the physiological effects occurring during warm water immersion.

The physiological effects of immersion are considered responsible for the therapeutic benefits reported in the European spa literature. The systematic review on balneotherapy cited 6 studies which were located in European spa resorts with the treatment consisting of warm water immersion, showering, underwater massage and mud baths/packs (Verhagen, 2000). Despite the methodological flaws highlighted by Verhagen (2000) all report positive benefits in pain reduction, clinical measures of disease activity and improvement in activities of daily living in patients with rheumatoid arthritis or osteoarthritis (Nguyen et al., 1997; Guillemin et al., 1994; Elykayam et al, 1991; Sukenik et al., 1990a and 1990b). What part the change of environment, diet and activity played in the overall benefit is unknown, but the rationale for the improvements were mainly related to the physiological effects of water immersion. Hydrotherapy may be regarded as a combination of warm water immersion and exercise. The known and diverse physiological effects associated with immersion provoke speculation that they may mediate therapeutic benefit. The next section describes the principles of immersion physiology. Comparing traditional hydrotherapy (exercise with immersion) and immersion per se, may help to identify the relative contributions of each to the therapeutic effect. The trial, described in Chapter 4 will examine the hypothesis that the combined effects of exercise and immersion provide greater therapeutic effect than immersion or exercise on their own.

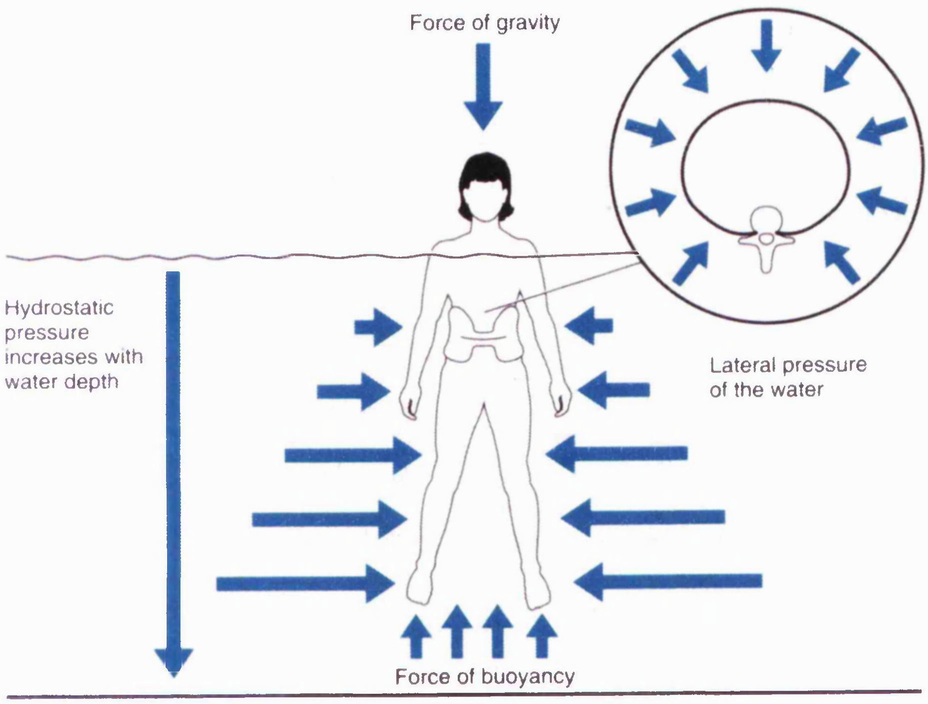
2.2. IMMERSION PHYSIOLOGY

At present hydrotherapy practice is underpinned by immersion physiology. For example, when appreciation of the effects of water temperature on heart rate (Weston et al., 1987) were absorbed the Hydrotherapy Association of Chartered Physiotherapists (HACP) recommended that hospital pools should be maintained at thermoneutral (34.5-35°C) rather than at higher temperatures.

Interest in immersion physiology arose, ironically from the space programmes of 1960-70s when it became important to understand the effects of weightlessness. It has contributed to the advancement of knowledge in many areas of physiology, and as appreciation of the immersion model developed further significant progress was achieved. The head-out water immersion model has been used, not only to study physiology in normal people but also in pathology, anthropometry, clinical and psychology. Studies utilising head-out water immersion as an investigative or diagnostic tool, have several features in common. Firstly, they generally refer to subjects, usually young and healthy, at rest. Description of the depth of immersion and the posture of the subject are vital as many physiological variables are influenced by these as well as duration of immersion. Finally, the temperature of the water must be recorded. Many of the early studies, investigating the effects of volume homeostasis, used thermoneutral temperatures (34.5-35°C), regarded as the temperature at which core body temperature is unchanged during resting head-out water immersion.

During upright water immersion the hydrostatic pressure on the body increases by 22.4 mmHg for each 30cm of depth and it is this which is considered to be the fundamental factor in the resulting physiological changes (Figure 2.4). It displaces blood from the vascular columns cephalad and produces a central volume expansion of approximately 700 mls (Arborelius et al., 1972). A further 200mls are added to the total blood volume via fluid shifts from intra- and intercellular compartments to the vascular space. This is a result of perturbation of Starling forces across capillary membranes, mediated by the hydrostatic pressure (Khosla and Dubois,1981). The extent of the volume expansion is dependent on water depth and posture, upright immersion to the neck providing the greatest hypervolaemia (Epstein, 1992; Hall et al., 1990). The volume increase is located in the central compartment, with the heart accepting approximately one-third and the lung vasculature the remainder (Risch et al., 1978). Central venous pressure increases by 3-15 mmHg and pulmonary arterial pressure by 10 mmHg (Gabrielson et al., 2000; Norsk et al., 1986; Christie et al., 1990; Arborelius et al., 1972). Distension of the volume receptors by this central hypervolaemia is considered to be the trigger to the cascade of diverse physiological reactions reviewed below.

Figure 2.4 – The pressures exerted on the body during head-out water immersion (Reproduced with permission from Bates and Hanson, 1996).



2.2.1. The Cardiovascular Response

The changes in the cardiovascular system occur immediately immersion is assumed and revert when the subject leaves the pool. They occur as a result of the hypervolaemia, mediated by the increased hydrostatic pressure. The augmentation in heart volume is reflected by increases of 34% and 50% in $\dot{Q}$ and stroke volume (SV) respectively with significant reduction in heart rate (HR) during thermoneutral head-out water immersion to the suprasternal notch (Gabrielsen et al., 2000; Park et al., 1999; Weston et al., 1987). The increase in SV is attributed, by Starling's law, to a significant elevation of both ventricular end diastolic and systolic volume (Christie et al., 1990). Alterations in HR during resting head-out water immersion are largely dependent on water temperature. In thermoneutral (34.5-35°C) and cool water, HR typically drops by approximately 10-15 beats.min^{-1}. In warm water, Weston et al. (1987), reported increases of 8 and 34 beats.min^{-1} at 37° and 39°C respectively. The bradycardia of lower water temperatures is probably mediated through cardiac vagal innervation, whereas the tachycardia associated with warm water may be related to falls in peripheral resistance and enhanced sino-atrial node depolarisation which are secondary to increased body temperature. Tachycardia and increased ventricular wall tension are known to increase myocardial oxygen consumption which may be undesirable in patients with cardiac dysfunction. Hence, the water temperature should be maintained at thermoneutral. Furthermore, the depth of immersion may be reduced to limit the degree of central volume expansion.

Despite numerous invasive and non-invasive investigations, there is a lack of unanimity regarding the effect of head-out water immersion on blood pressure (BP). BP is the product of $\dot{Q}$ and total peripheral resistance and, is the primary regulated variable within the cardiovascular system. Therefore, to enable BP to remain unchanged in the face of increasing $\dot{Q}$ during thermoneutral head-out water immersion, peripheral resistance reduces by approximately 35% (Weston et al., 1987). In his review Epstein (1992) concluded that BP is probably unaltered during head-out water immersion but, it is plausible to speculate that reported changes in BP are due to errors in technique and lack of posture standardisation (Park et al., 1999; Epstein, 1992; Weston et al., 1987).

The increased $\dot{Q}$ is redistributed to the skin and muscle beds rather than the splanchic (Blyden et al., 1989) or renal circulations (Epstein, 1976). Balldin et al. (1989), showed that blood flow increased by approximately 127% during thermoneutral chest deep-water immersion. An increase in blood flow would suggest that oxygen transport is enhanced which may facilitate aerobic pathways. However, the increased hydrostatic pressure may limit peripheral blood flow, especially to the legs, and this maldistribution may shift cellular respiration towards anaerobic metabolism. Therefore, only some of the effects of head-out water immersion may enhance cardiovascular dynamics.

2.2.2. The Haemodilutional Effects

The mobilisation of oedema induced by water immersion has been observed for some time: "A Scotsman in an ascites, was cured. By his girdle which I saw, he fell six inches in 5 days, pissing freely all the time" (Sutherland, 1764). Von Diringshofen (1948) is credited with the theory that the pressure-gradient induces an imbalance of the Starling forces controlling fluid filtration and reabsorption between the capillary and interstitial tissues. A decrease of vascular transmural pressure caused by the hydrostatic pressure results in a decrease in capillary diameter which increases the resistance to blood flow and effects a decrease in venous pressure. These effects decrease capillary filtration and increase end-capillary (or venular) reabsorption of interstitial and intracellular fluid resulting in a shift of fluid from interstitium to intravascular space representing a haemodilution (Yamazaki et al., 2000; O'Hare et al., 1985; Khosla and Dubois, 1979; Crane and Harris, 1974). Yamazaki et al., (2000) noted that this haemodilutional effect was maximal, as measured by mass density of blood samples, after 20-25 minutes of upright immersion and was not influenced by water temperature. Haematocrit values and erythrocyte density also fell but plasma osmolality remained unchanged indicating that the increase in plasma volume was induced by an isotonic fluid shift from extravascular space. O'Hare (1984), using less sophisticated technology than Yamazaki (2000), reported significant reductions in plasma viscosity in 7 RA patients and speculated that this may positively modify the rheumatoid process.

2.2.3. The Respiratory Effects

Thoracic vascular engorgement and elevation of the diaphragm resulting from head-out water immersion decreases lung compliance thereby altering pulmonary function and increasing the work of breathing. It is therefore possible that patients with inspiratory muscle weakness may prefer to limit immersion to below the thorax. Vital capacity (VC) is reduced by approximately 10% although fluctuations have been noted to be temperature dependent (Brechat et al., 1999; Risch et al., 1978). Choukroun et al. (1989) reported increased VC in water at 40°C. This was associated with a decrease in electromyographic amplitude of the rectus abdominis. The authors suggested that abdominal wall stiffness was reduced at higher temperatures, thus enabling a greater VC. Central vascular engorgement may alter the ventilation-perfusion ratio and affect arterial oxygen concentration. Falls in arterial oxygen concentration and increases in alveolar-arterial differences have been reported by a number of authors (Lollgen et al., 1976; Cohen et al., 1971) but disputed by Derion et al. (1992), and Choukran and Varene (1990) who found no significant changes.

It is generally accepted that oxygen consumption is not affected by thermoneutral water immersion but increases significantly in water below neutral (Choukroun et al., 1989; Strong et al., 1985) due to shivering thermogenesis. The larger $\dot{V}O_2$ during cold water immersion combined with an enhanced $\dot{Q}$, mediated principally by vasoconstriction, has been shown to increase O_2 extraction by the tissues (Choukroun and Varene, 1990). Oxygen transport is enhanced above thermoneutral temperatures due to the increased $\dot{Q}$ resulting from increased hydrostatic pressure and body heating, but O_2 extraction is unchanged as $\dot{V}O_2$ remains similar to that in thermoneutral water.

2.2.4. The Renal Response

The renal effects of head-out water immersion, secondary to distension of the volume receptors via central volume expansion, have been well documented by Epstein (1992). The increased diuresis starts within the first hour of immersion and peaks in the second whilst the natriuresis peaks in the fourth or fifth hour. Increased urinary excretion of potassium and calcium has also been reported (Bisson et al., 1992; Epstein, 1978b). These events occur without significant change in either glomerular filtration or in total plasma renal flow which suggests that the mechanisms act at the level of the renal tubules or collecting ducts. Epstein (1992), has shown that the mechanisms are neurohormonally mediated as noted by reductions in anti-diuretic hormone, suppression of the renin-angiotensin-aldosterone system and attenuation of renal sympathetic nervous activity. The renal effects of head-out water immersion are depth and temperature dependent (Nakamitsu et al., 1994; Norsk et al., 1986). However, the significance of these effects may not be important for patients undergoing hydrotherapy as the immersion times rarely exceed 1 hour.

2.2.5. Neuroendocrine Activity

Head-out water immersion has been shown to reduce peripheral venous tone and reflexly dilate the renal afferent arterioles. This is attributed to a generalised suppression of the sympathetic nervous system, required to maintain haemodynamic homeostasis and has been conclusively demonstrated by Mano (1990). Using microneurographic techniques, Mano showed that muscle sympathetic nervous activity from the tibial and peroneal nerves was reduced during head-out water immersion. The degree of suppression is related to the extent of central volume expansion. For example, muscle sympathetic nervous activity was reduced by approximately 24% and 73% during waist and neck deep head-out water immersion respectively, compared to standing on land. Furthermore, plasma noradrenaline, a crude measure of sympathetic activity, was significantly reduced within the first hour of thermoneutral immersion (Gabrielsen et al., 2000; Connelly et al., 1990; Norsk et al., 1990; O'Hare et al., 1986). Norsk et al. (1990) demonstrated concomitant increases in stroke volume and central venous pressure, suggesting that the mechanism was linked to the stimulation of low-pressure baroreceptors by the central hypervolaemia. This was recently confirmed by Gabrielsen (2000) who observed an inverse relationship between plasma noradrenaline suppression and water depth.

Two studies, one of which included RA patients, have shown that head-out water immersion reduces plasma ß–endorphin (Hall, 1993; Coruzzi et al., 1988). Whilst the functional significance of opioid peptides remains uncertain Ekdahl et al. (1994), reported that high levels of ß–endorphin are associated with greater pain and a more negative global assessment. Therefore the neuroendocrine consequences of head-out water immersion may contribute to the pain reduction claimed for hydrotherapy.

2.2.6. Thermoregulation

Body temperature regulation is different in water than in air because during immersion heat cannot be lost through evaporation of sweat, except for those areas of the body unimmersed. Due to the greater heat conductivity of water, heat exchanges are much faster (Pirnay et al., 1977). Core body temperature changes are related to water temperature, speed of movement or exercise intensity and body fatness (Sagawa et al., 1988). As such, heat may be gained, lost or remain the same. Head-out water immersion in thermoneutral water (34.5-35°C) does not alter core body temperature, but after immersion for one hour in water above 36°C, rectal temperature increased and in water below 33°C shivering occurred (Craig and Dvorak, 1966).

Maintaining core body temperature when exercise is added alters the thermoneutral temperature of the water from 17°C to 34°C depending on the intensity of exercise and body fatness (Craig and Dvorak, 1968; Costill et al., 1967). The recommended temperature for exercising in water depends on the purpose of the exercise. Recreational pools are maintained at approximately 28°C whilst therapeutic pools range from 34.5-36°C. The higher water temperatures of hydrotherapy pools is required because the user populations are typically incapacitated and the rehabilitation programmes utilise varying intensities of exercise. Therefore, patients may rapidly lose heat during periods of low levels of exercise intensity and increase core body temperature during intense activity. A balanced exercise programme, alternating low and high levels of exercise intensity should therefore be adopted to offset the deleterious effects of heat stress.

2.2.7. Summary

Head-out water immersion causes a variety of profound effects on the physiological systems investigated to date. These include the cardiovascular, respiratory, renal, endocrine and sympathetic nervous systems. The rationale for clinical and functional improvements following hydrotherapy is unknown. Whilst sceptics might dismiss any benefits as a psychological placebo type response, the physiological effects of immersion make speculation for a physiological basis compelling. Presently, no study has attempted to isolate the effects of immersion from those of exercise and therefore a randomised controlled trial is proposed to examine the components of hydrotherapy. Such a study may help to clarify the therapeutic responses to the single entities and to the combination thus helping to rationalise hydrotherapy programmes. To overcome the limitations of previous studies and to conduct such a study requires the use of reliable and valid measures which are now reviewed.

CHAPTER 3

REVIEW AND SELECTION OF MEASUREMENTS

3.1. INTRODUCTION

Randomised clinical trials are only as good as their outcome measures, of which there are a large number in clinical trials of RA. This, together with dissent among researchers as to which is best in monitoring outcome, testifies to the lack of a single measure or gold standard (Bombardier et al., 1982). It is perhaps simplistic to aspire to a single measure given the complexity and heterogeneity of the rheumatoid process and its ensuing functional and affective consequences. The lack of such a measure has forced the use of multiple outcome measures which cover the constructs of impairment, disability and handicap using a variety of clinical, laboratory and functional instruments.

The range of measures from which to choose is based on the hypothesis to be tested, and the relative merits of each measure. Ideally all measurements should meet the minimum standards of "good" measurement theory which include reliability, validity, sensitivity, applicability, practicality (eg: ease of use, cost, ease of scaling/scoring methods) and comprehensiveness. Unfortunately, many of the available measures do not meet all of the criteria, and an understanding of the strengths and weaknesses of each must be considered before an informed selection can be made. Furthermore, taking into account the standardisation of the test environment, influence of circadian rhythms, tester skill and subject cognition are all required to minimise measurement error. For example, joint pain, stiffness, articular index and grip strength have been shown to alter depending on the time of day, and with minimal activity in the early afternoon (Harkness et al., 1982). This has implications for the timing of measures, and suggests that individuals should be tested at the same time of day on subsequent sessions.

The aims of physiotherapy in RA are two fold: to maintain or increase independence and promote the best quality of life. Therefore measurements which reflect these objectives are required. However, independence and quality of life are complex issues and no single measure can capture their intrinsic components. Therefore a battery of tests is required to identify the variables of interest. Furthermore, hydrotherapy may have a disease modulating role and so including some measures of disease activity would be prudent.

3.2. MEASURES OF PHYSICAL FUNCTION

Physical function tests are objective measures of impairment and disability. They usually require the patient to produce their best performance and therefore standardized test conditions and procedures (which are clearly understood by the patient) are a prerequisite of a valid endeavour. A great many tests of physical function exist but only those traditionally accepted as part of the physiotherapist's repertoire will be considered.

3.2.1. Range of Movement

Measuring the range of joint motion is an integral part of physiotherapy and one of the most commonly employed assessment techniques (Miller, 1985). The importance of evaluating joint range of movement has been underlined by research showing that disability is significantly influenced by limited joint motion (Cox and Carr, 1991; Badley et al., 1984). A number of devices exist for the measurement of range of movement but the universal or manual full-circle goniometer is the most popular one because of its ease of use and low cost. Its criterion validity has been established using X-rays and intraclass coefficients of 0.98 have been established for normal knee joints between subject and X-ray readings (Gogia et al., 1987). The reliability of the universal goniometer has been established in many studies as good to excellent (Brosseau et al., 2001; Goodwin et al., 1992; Gogia et al., 1987; Gajdosik and Bohannon, 1987; Stratford et al., 1984; Rothstein et al., 1983). For example, Brosseau et al. (2001) reported high intra-rater reliability for knee motion in 60 patients with various knee pathologies (r =0.9). Intra-rater reliability is higher than inter-rater (Brosseau et al., 2001; Smith and Walker,1983). Therefore, a standard universal goniometer was used to measure joint motion in the trial described in Chapter 4.

3.2.2. Muscle Performance

The many methods of testing strength testify to the diversity of muscle performance (muscle action, speed and range of movement) and selection of measurement tool should be based on the specific aspects of muscle function of interest. Manual muscle testing depends on a subjective 12–point rating scale which is unable to discriminate accurately small variations in strength and is therefore unsuitable for the research presented in this thesis (Frese, Brown and Norton, 1987; Wadsworth et al., 1987). Objective, quantitative information on muscle strength is available using a variety of devices as defined by Bohannon (1987) such as strain gauges and isokinetic dynamometers but these devices require specialized and expensive equipment. Furthermore, they suffer from a lack of protocol standardization and normative data (Gleeson and Mercer, 1996; Mayhew and Rothstein, 1985; Watkins, 1993; Bohannon, 1987 and 1986). Muscle performance testing is difficult and this trial was designed to mimic current practice in terms of treatment duration so it is unlikely that significant strength changes will occur. For this reason it was inappropriate to incorporate specific muscle testing procedures in this particular study.

3.2.3. Grip Strength

Many devices are available to measure grip strength but the most commonly used are the ones that test isometric grip. Grip strength monitors consisting of an inflated bag which the patient squeezes are preferred, over solid handle transducers, for patients with RA because they are better able to fit their hand to the bag, especially in the case of deformity (Myers et al., 1980). Grip strength measurement is influenced by many factors including joint stiffness, joint and muscle integrity, pain, diurnal variation, patient motivation, standardisation of instrument, testing protocol, posture and test instructions (Balogun et al., 1991; Lee et al., 1974; Harkness et al., 1982; Levy and Dick, 1975). The intra-rater and test-retest reliability of grip strength has been reported as good ($r>0.8$) by a number of authors (Jones et al., 1991; Pincus et al., 1991; Solgaard et al., 1984; Lee et al., 1974). Lee et al. (1974), reported that changes in grip strength over 9mmHg may be regarded as true change as opposed to assessor error. Grip strength has been shown to increase in trials of aerobic conditioning and "planned activity" (Minor et al., 1989; Stenstrom et al., 1991; Alexander et al, 1983) suggesting that grip strength may be a sensitive measure of functional change.

Grip strength is used as a quick, non-invasive clinical measure of disease activity in RA on the basis of negative moderate to low correlation coefficients with biochemical markers of disease activity (Spiegel et al., 1987; Rhind et al., 1980). Spiegel et al. (1987), argued that grip strength is also an objective functional measure on the basis of correlational findings. This research is strengthened by the reporting of relationships between grip strength and hand function and the importance of hand function to functional ability and work status (Minor and Hewett, 1995; Callahan et al., 1992). Grip strength was therefore included in the trial as a measure of disease activity and function.

3.2.4. Physical Functional Performance Tests

Direct observation and timed performance of functional tasks, such as 50 foot walk time (Pincus et al., 1991; Spiegel et al., 1987), muscle function index (Ekdahl et al., 1989), shoulder function assessment (Bostrom et al., 1991 and 1995) timed-up-and-go (McKeeken et al., 1999) have been developed as a means of assessing physical or sensory-motor function. Many of these tests rely on patients willingness to participate and sincerity of effort and, at times, subjective judgments by the therapist which introduces error into the measurement process (Beattie, 2001). Furthermore many are time consuming to conduct, may be tiring for the patient, require therapists, experienced in the observation and scoring techniques and the test may not encompass all of the domains of interest. Despite the intuitive attractiveness of these instruments to measure important indices of functional ability their use in research is not as widespread as self-report questionnaires, which have the ability to capture all facets of perceived functional capacity (physical, mental, emotional and social) within the one measure. Therefore, functional performance tests were not included in the trial to be described.

3.2.5. Self-report Functional Capacity

Jette (1985) stated "focusing on observable physical signs and symptoms to evaluate interventions that purport to have an impact on functional status is narrow and much too limiting". As physiotherapists are concerned with encouraging the best functional capacity or quality of life possible within the restrictions of the disease process measures which go beyond the level of impairment are essential. Disability represents one end of the functional ability continuum and may be defined as a diminished capability of the individual in function or performance. Functional ability/disability comprises a complex interaction between physical (eg: physical health status, physical function), mental (eg: intellectual, cognitive or reasoning capabilities), emotional (eg: level of anxiety, depression, life satisfaction, self-esteem) and social dimensions (eg: performance of social role, community integration) according to individual's value systems (Bowling, 1999). These dimensions are subsumed, to a greater or lesser extent, in instruments which measure health-related quality of life. Thus its measurement is complex and the favoured method is by self-report questionnaire.

Three types of questionnaire have been developed: generic, dimension and disease specific (Fletcher et al., 1992). Generic questionnaires (eg, the Sickness Impact Profile) cover a broad range of quality of life dimensions and are useful for comparing among different disease groups and therefore were not used in the trial described in Chapter 4. Dimension specific measures are limited to the measure of a single construct. For example the Profile of Mood States measures psychological well being. They are therefore unsuitable in providing a profile of functional status. Disease specific measures include only relevant dimensions and thus patient acceptability and content validity may be enhanced. Disease specific questionnaires for patients with arthritis have been developed. Two which have undergone the stringencies of validation and reliability testing are the Arthritis Impact Measurement Scale (AIMS) and the Health Assessment Questionnaire (HAQ). The HAQ assesses the degree of difficulty for a variety of functional activities and therefore is unsuitable in a randomised clinical trial to assess the physical and psychological efficacy of hydrotherapy (Fries et al., 1982).

The original AIMS questionnaire (Meenan et al., 1980) was designed to assess health status in patients with rheumatic diseases. It has been found to be a reliable, valid measure sensitive to clinical change (Meenan et al., 1984; Potts and Brandt, 1987; Anderson et al., 1989). The revised and expanded version of the self-administered questionnaire (Meenan et al., 1992) is divided into 12 subscales: mobility level, walking and bending, hand and finger function, arm function, self-care tasks, household tasks, social activity, support from family and friends, arthritis pain, work, level of tension, and mood. Additional sections concern satisfaction with function, attribution of problems to arthritis, comorbidity, and designation of priority areas for improvement. It is easy to administer and takes the respondent approximately 15-20 minutes to complete. It relies on good literacy skills and avoids response bias by careful wording and coding procedures. A normalization procedure converts the subscale scores to a 0-10 range, 0 representing good quality of life and 10 poor (Meenan et al., 1980). A total score may be derived by summation of the normalized scores divided by the number of subscales and is ordinal in type. In addition 3 major health status components may be obtained: physical function (derived from the mobility, physical activity, dexterity, household and social activities), psychological status (derived from anxiety and depression scores) and pain (Mason et al., 1988). The AIMS has been used extensively in studies evaluating the efficacy of drugs and has been used by others evaluating the efficacy of exercise in arthritis (Hakkinen et al., 1999; van den Ende et al., 1996; Minor et al., 1989). The AIMS was therefore included in the study as a suitable measure of physical and psychological function.

3.3. THE MEASUREMENT OF PAIN.

Pain is a subjective experience of fluctuating status and is influenced, not only by pathophysiological events, but by behavioural, socio-economic status, cultural and historical variables. Patients with RA report pain to be one of the most troublesome aspects of the disease, and it may be attributable to a variety of causes (Stenstrom et al., 1990; Parker et al., 1988). These include sensitization of nocioceptors by inflammatory mediators, pressure caused by swelling and mechanical aberrations. Of necessity the measurement of pain is subjective, and self report methods are more relevant and possess greater validity to the clinical researcher than experimentally induced pain (Main and Waddell, 1989).

A number of methods have been developed including descriptive Likert type scales (which grade pain on a 0-5 scale from no pain to agonizing pain) and percentage and fraction methods which, ask the patients to consider initial pain intensity as 100% and to decrease or increase as appropriate on subsequent occasions. These methods lack sensitivity (Huskisson, 1976). Pain diaries have been proposed but compliance is difficult to control and analysis under-developed (Main and Waddell, 1989). The visual analogue scale (VAS) is a 10cm line which measures the continuum of pain intensity. Patients are asked to mark the line in a position which corresponds to their pain. The concurrent and construct validity of the VAS has been tested by correlating responses with other pain rating scales and following analgesic intervention (Jensen et al.,1986; Downie et al.,1978; Scott and Huskisson,1976). Reliability and sensitivity have been reported as satisfactory (Scott and Huskisson, 1976; Downie et al., 1978; Jensen et al., 1986). However, a number of criticisms of the VAS have been made. It has been noted that patients tend to over or underestimate their pain thereby avoiding ±2cm from the midpoint (Dixon and Bird, 1981; Bird and Wright, 1982). Some patients find the concept of VAS incomprehensible but the main problem is that it fails to reflect the complexity of the pain experience and for this reason the McGill Pain Questionnaire was developed.

3.3.1. The McGill Pain Questionnaire

The McGill Pain Questionnaire is a multidimensional self-report measure of pain that was developed to encompass elements of pain intensity and affect. It consists of 20 verbal rating scales covering sensory (eg: temporal, spatial, thermal), affective (eg: emotion-based words such as tension, fear) and evaluative (subjective overall intensity) dimensions. The adjectives within each scale are weighted in terms of pain intensity (Melzack, 1975). The patient must choose one word from each scale that best describes their present pain. A number of indices may be derived: the number of words chosen, the sum of weighted values of words selected (Pain Rating Index) and the Pain Rating Index divided by the number of words chosen. Each of the indices may be computed for the questionnaire as a whole and for each of the 3 subscales. Because development of the original questionnaire did not involve RA patients the content validity was questioned by Skevington (1979) who constructed a modified form, consisting of unrestricted access to 69 descriptors which can be completed by the patient in 5 minutes.

Extensive testing demonstrates that the measure is valid and reliable (Wilkie et al., 1990; Reading, 1984). Face validity has been assumed as patients often express relief when given a descriptor that matches their inarticulated feelings of pain. Construct validity has been determined by assessing the relationship between McGill Pain Questionnaire scores and measures of psychological state. Concurrent and predictive validity have been examined in relation to analgesia requirements and correlations to other pain measurement instruments. Discriminant validity has been established by the ability of the questionnaire to distinguish between different patients groups. It seems that chronic pain patients select affective orientated words with greater frequency than patients in acute pain reinforcing the importance of emotional factors in the experience of chronic pain patients, such as RA. In terms of reliability, alternate forms, test-retest (consistency of test over time) and sensitivity to standardized stimuli have been reported as satisfactory. Despite its widespread use normative data on the McGill Pain Questionnaire is limited (Wilkie et al., 1990) and clinically significant differences between pre and post-intervention have yet to be consensually deduced.

The McGill Pain Questionnaire has been used in a wide variety of pain conditions including arthritis. Presently, the McGill Pain Questionnaire is judged the most popular measure of pain used in clinical trials and therefore including it in a trial of hydrotherapy may allow comparisons with other studies.

3.3.2. The Beliefs in Pain Control Questionnaire

Previous research has suggested that beliefs about pain control may be as important in controlling pain as the pain itself (Bowers, 1968). Additionally, there is some evidence that strong beliefs in internal or personal pain control are more often associated with better physical and psychological health than beliefs that pain is beyond personal control or is external (Skevington, 1995). The Beliefs in Pain Control Questionnaire was designed on the basis of the concept of locus of control, a term used to refer to the perceived source of control over one's behaviour. In health terms, looking at beliefs about causation of their disease in RA patients has led to a distinction between those who believe in their personal ability to control events (internal locus) and those who believe events are beyond their control (external) (Skevington, 1990). The external locus has been further divided into those external causes which are thought to be governed by other people (in the case of health other people are powerful doctors) or factors such as chance (chance happenings). The Beliefs in Pain Control Questionnaire has been standardised for use with patients with RA and demonstrates adequate reliability and validity (Skevington, 1990). Its 13 items, ranked according to a 6-point Likert type scale, anchored "strongly disagree" to "strongly agree", constitute the 3 subscales, reflecting the 3 dimensions of the locus of control. The internal scale measures beliefs that pain is within one's own personal control: so, a high score indicates strong internality. The other 2 scales measure belief that pain is controlled by factors which are beyond or outside one's personal control : the powerful doctors scale examines beliefs that pain control is in the hands of the doctors, and the chance happenings scale evaluates beliefs that pain is controlled by chance happenings or misfortune. The maximum response for each subscale is 6 with high scores reflecting high internality or externality, depending on the subscale.

Whilst hydrotherapy is held in high esteem as an analgesic convincing scientific evidence is lacking. This may be a function of poorly designed studies and/or a lack of responsiveness in the pain measures used. However, as beliefs in pain control may be important to pain experienced and may precede changes in pain symptoms it could be important to include measures of beliefs in pain control in a prospective study of hydrotherapy. As strong internality is associated with less reported pain strengthening this dimension and/or reducing externality may reflect in improved McGill Pain Questionnaire scores.

3.4. MEASURES OF DISEASE ACTIVITY

Assessment of disease activity by the physician is performed to monitor the severity and course of RA and to evaluate the impact of drug therapy. Given the associations between disease activity and functional and psychosocial performance (Welsing et al., 2001), it is paramount that disease activity is reduced, or at the very least, unaffected by physiotherapy interventions. Therefore monitoring the disease activity in hydrotherapy trials is important for safety reasons. Furthermore, it enables examination of a possible role for physiotherapy in disease modulation. For example, physical function may be impeded by morning stiffness and the longer the duration of stiffness the greater the degree of dysfunction. Secondly, some physiotherapeutic modalities (eg, low level laser therapy) have shown immunomodulatory effects in patients with RA (Palmgren et al., 1989) and hydrotherapy has been shown to have beneficial effects on some clinical indices of disease activity, although not on laboratory markers (Minor et al., 1989; Sukenik et al., 1990b). Disease activity cannot be measured by one single variable, rather a combination of clinical, laboratory, radiological and physician and patient global assessment is used to form an judgment of the overall inflammatory activity.

3.4.1. Morning Stiffness

Morning stiffness is characteristic of RA and its duration (recorded in minutes) is regarded as an indicator of disease activity. The patient is asked if morning stiffness is present and if so to recall how long it lasts after rising. Therefore, good memory recall is required. It is assumed that morning stiffness measures global stiffness but patients may have difficulty summating various stiff joints to give a whole and their response may be governed by the most affected joint. Morning stiffness considers duration only; severity is ignored by the clinician but it is uncertain if patients do likewise. Rhind et al. (1987), point to the relationships between stiffness, pain and limited movement as contributing to the patient's ambiguous definition. Therefore the validity of this measure is uncertain and a new operational definition, endorsed by patients is required to gain a more meaningful insight into what is meant by morning stiffness (Lineker et al., 1999). However, it remains one of the best available options for gaining insight into joint stiffness and has been used in previous studies on hydrotherapy therefore incorporating it into the randomised clinical trial will enable comparisons of similar studies.

3.4.2. Articular Indices

Articular indices provide a standardised and quantifiable clinical assessment of joint signs, such as tenderness and/or swelling. The Ritchie index is regarded as a reliable and valid measure of joint tenderness (Prevoo et al., 1993; Ritchie et al., 1968; Thompson et al., 1991) which differs from the American Rheumatism Association and Lansbury index in that the pain response is graded as opposed to mere presence/absence. Furthermore, the Ritchie Index is a measure of tenderness and does not consider the number of swollen joints. It is therefore correlated to pain scores but not laboratory measures of inflammation (Gaston-Johansson and Gustafsson, 1990; Thompson et al., 1987). Digital pressure is applied to the joint margins of the upper and lower limbs (and in the case of the cervical spine, hip, talocalcaneal and midtarsal joints passive movement) and the patient's response is graded on a 3 point scale: 0 = not tender, 1 = verbal report of tenderness, 2 = tender and wince, 3 = tender, wince and withdraw). Summation of the responses provides a single measure of joint tenderness with a maximal value of 78 from 53 joints, grouped into 26 units. Whilst the inter-reliability of the Ritchie index is poor (Thompson et al., 1991; Hart et al., 1985), perhaps because of differences in strength of the pressure stimulus resulting from grading, the intra-rater has been shown to be good and the grading system increases its sensitivity (Hernández-Cruz and Cardiel, 1998; Ritchie et al., 1968). Using a number of statistical techniques for assessing intra-observer test-retest agreement Hernández-Cruz and Cardiel (1998), showed excellent levels of association ($r = 0.92$, ICC= 0.49, $\kappa w = 0.83$). This test is quick to perform and has been shown to be sensitive to change in studies evaluating the efficacy of physiotherapy treatments (Minor et al., 1988; Stenstrom et al., 1991; Sukenik et al., 1990a and 1990b). The Ritchie index was incorporated into the trial for this reason.

3.4.3. Laboratory Measures

C-reactive protein (CRP) is the most commonly used acute phase protein for the laboratory monitoring of disease activity (ie, quantification of inflammation) and response to therapy in RA (Richardson and Emery, 1996). It indirectly reflects the inflammatory process and is favoured above erythrocyte sedimentation rate (ESR) because of its sensitivity and short half life. Furthermore, it is not spuriously elevated by anaemia which is common in RA. CRP, primarily synthesized in the liver, is stimulated by circulating cytokines (especially interleukin 1 and 6) originating from the inflamed synovium. Therefore there is a strong and positive correlation between serum CRP and synovial fluid cytokines. The function of CRP remains uncertain but appears to activate the complement pathway and nonspecific host defense mechanisms. Low CRP levels are associated with good physical function and slow radiological progression and persistently elevated levels are correlated with poor outcome (Devlin et al., 1997; Otterness, 1994). Therefore, as well as being useful for monitoring purposes CRP has a prognostic function. In normal individuals its concentration is less than 10mg/l but in the majority of patients with RA CRP is elevated, with levels sometimes reaching several hundred mg/l. It may be measured using a variety of methods including the semiautomated latex method (Otterness, 1994). Its inclusion in this trial is justified because studies on balneotherapy suggest that modification of disease activity occurs (Elkayam et al., 1991).

3.5. SUMMARY

This chapter reviewed current knowledge on the measurement tools that would be most appropriate to investigate the efficacy of hydrotherapy in patients with RA. The lack and limitations of previous research into hydrotherapy was addressed in Chapter 2 and, the contribution of the physiological effects of immersion to therapeutic effect was discussed. As a result the hypothesis that hydrotherapy would provide superior therapeutic benefit than either exercise or immersion *per se* was formulated. The next chapter (Chapter 4) details the study to test this hypothesis.

CHAPTER 4

A RANDOMISED AND CONTROLLED TRIAL OF HYDROTHERAPY IN RA

4.1. INTRODUCTION

Chapter 2 discussed the use and rationale of hydrotherapy in patients with RA. It concluded that the scarce research available did not provide unequivocal evidence to support the claims made on behalf of hydrotherapy because the study designs were of poor quality. Given the lack of evidence of efficacy and its continuing popularity a well designed trial is overdue. Furthermore, speculation that the immersion component of hydrotherapy may contribute wholly or partially to the benefits claimed by patients with RA deserves scrutiny because this may have implications for treatment programmes. Therefore the present study was designed to test the hypothesis that the combined elements of water immersion and exercise in hydrotherapy were therapeutically superior to either evaluated singly. Therapeutic benefit was defined as improvement in measures of disease activity, physical and psychological function.

4.2. METHODS

Randomised controlled trials remain the gold standard in providing causal evidence with maximal internal validity (Grimes and Schulz, 2002). Evidence-based practice relies upon good quality systematic reviews and meta-analysis, both of which consider randomised clinical trial exclusively. Therefore the design employed to test the present hypothesis used a randomised clinical trial. Given the definition of hydrotherapy as a combination of 2 components and to test the hypothesis rigorously a 4 cell design was adopted. Therefore 3 control groups and one experimental group (hydrotherapy) were included. An exercise only (land exercise) and an immersion only (IMM) group enabled separation of the hydrotherapy components. Hydrotherapy and land exercise (LE) group sessions require direct supervision of the physiotherapist whereas seated immersion, in an earlier pilot study had taken the form of a social support group (Hall, 1993). Therefore, to equalize physiotherapy input and to prevent against self-exercise the IMM group performed a relaxation procedure in the water. A third control group was required to control for the effects of relaxation out of the water (Land Relaxation). Therefore 4 groups were convened in a between subjects factorial model (Table 4.1).

Table 4.1 - Patients were randomly allocated to one of 4 groups

	Hydrotherapy (H)	Immersion (IMM)	Land exercise (LE)	Land Relaxation (LR)
Water	+	+	-	-
Exercise	+	-	+	-
Relaxation	-	+	-	+

4.2.1. Subjects

The sample size was calculated from previous data collected in an earlier pilot study on the efficacy of hydrotherapy in patients with RA (Hall, 1993). The Ritchie index is a measure of joint tenderness and has been shown to correlate well with pain scores (Thompson et al., 1987). Furthermore, significant reduction of joint tenderness after hydrotherapy in 11 patients with RA was reported in the pilot study (Hall, 1993). Therefore, this measure was used to estimate sample size. The standardized difference for the Ritchie index was calculated by the mean pre- to post-difference divided by the standard deviation (5 ± 10.2) and with alpha set at 0.05 and power at 0.8. A nomogram showed that a sample size of 140 would be required (35 per group) [Altman, 1991].

Patients with RA who presented with functional classes I – III were included (Hochberg et al., 1992). To ensure entry of patients with chronic active RA only those with extensive disease as characterized by the involvement (ie, pain and tenderness) of at least 6 joints at pre-test were admitted. Study entry was also limited to those patients who were maintained on a stable drug regimen for a period of 30 days in the case of non-steroidal anti-inflammatories (NSAIDs) or 3 months for disease modifying antirheumatic drugs (DMARDS). Patients who had received intra-articular corticosteroid injections or physiotherapy treatment within 30 days of assessment for the study were excluded, as were patients who had joint replacement surgery within 6 months. Patients with a history of any known condition contraindicating exercise therapy or immersion in water (ie. recent myocardial infarction, resting angina, or fear of water) were also excluded, as were patients with uncontrolled pathology (eg, epilepsy) .

One hundred and forty-seven patients with RA who met the entry criteria were recruited to the study. Seven patients dropped out after 1-2 treatments and in accordance with the sample attrition policy were replaced. Reasons for dropping-out included transport difficulties, shortage of time, lack of interest and being allocated to an unwanted group. Drop-outs occurred mainly in the land relaxation (LR) group (n=5) and hydrotherapy group (n=2). Four patients, of which 3 (less than 10% of the group) were in the hydrotherapy group and one in the IMM group were withdrawn from treatment due to a flare up of their RA or a corticosteroid injection. The number of treatments given before withdrawal ranged from 1 – 5 and all patients completed a second assessment which was included in the statistical analysis. One patient withdrew following her 8 treatments of land exercise with a myocardial infarction and was therefore unable to attend for post-testing. Thus 139 patients completed the study with the land exercise group consisting of 34 patients.

4.2.2 Ethical Considerations

Ethical approval for this study was granted by the Bath District Research Ethics Committee.

4.2.3. Study and Treatment Protocol

Patients with RA, identified by their diagnoses from the database at the Royal National Hospital for Rheumatic Diseases, Bath, received a letter giving brief details of the study and inviting them to express interest by returning a tear-off slip in the SAE provided. Patients who responded positively received a telephone call from the researcher who explained the study protocol and, if appropriate asked some questions to establish the patients suitability (Appendix 4.1). Patients who met the initial entry criteria were invited to the hospital and following successful completion of the entry criteria and ethical permission forms were recruited to the study (Appendices 4.2 and 4.3). Pre-test measures were then completed.

Restricted random assignment following trial entry to one of the 4 groups was achieved by an independent co-ordinator using a random numbers table and groups of subjects in blocks so that equal numbers of subjects were allocated to each of the 4 groups (Grimes and Schultz, 2002; Kazdin, 1992). In this way the researcher remained "blind" to the treatment allocation. Patients were warned at every testing session not to reveal which treatment they had received.

All interventions took place in the gymnasium or hydrotherapy pool at the Royal National Hospital for Rheumatic Diseases, Bath. Patients were convened in small groups of 4 or 5. Three physiotherapists were trained to carry out the standardized exercise regimen and relaxation programmes. In accordance with standard therapeutic practice, the exercise sessions lasted for 30 minutes; the relaxation interventions were designed to last an equivalent length of time. Evidence from the pilot study suggested that 8 sessions of hydrotherapy (H) and land exercise (LE) would constitute a suitable course of treatment, and be in line with existing clinical practice. For reasons of patient fatigue, all interventions were limited to 2 sessions per week therefore patients attended for 4 consecutive weeks.

A generalized whole body exercise programme was designed for the H and LE groups with the broad aims of increasing peripheral joint range of movement and muscle strength of the upper and lower limbs (Appendix 4.4). The type of exercises and number of repetitions were standardized in consultation with the treating physiotherapists. The speed and resistance of each exercise was constantly monitored by the physiotherapist so that the patient was challenged at all times, as occurs in normal practice.

An adapted and updated version of Jacobsen's progressive relaxation technique (Jacobsen, 1938) including some mental imagery tasks, was tailored for use with arthritis patients in the two non-exercise groups (IMM and LR). Following training, the physiotherapist read from a relaxation script at each session. LR patients relaxed in a quiet darkened room on comfortable mats, or exercise couches, and with optional pillows supporting the head and knees. Patients in the IMM group relaxed in the pool whilst sitting with the legs dependent on weighted chairs. The water was maintained at the usual water temperature of 36°C and patients were immersed to the suprasternal notch.

Continuation of their treatment at home was not actively encouraged as it was recognized that transference of water-based exercises to land may have been difficult for the patient. However, if patients asked their physiotherapist if they should continue their treatment at home the physiotherapist agreed that this was possible. At both the post-test and follow-up assessments the researcher asked patients if they were practicing anything they had learnt from their treatment.

4.2.4. Assessments

Pre-, post test and 3 month follow-up assessments were completed by the researcher, who remained "blind" to the intervention. Patients were assessed on each occasion at the same time of day to control for diurnal variations in measurement and using the same order of testing (Bellamy et al., 1991; Harkness et al., 1982). The measures, detailed below, spanned physical function, disease activity, pain and self-report health status.

4.2.4a. Measures of Physical Function

Two measures of physical function, range of movement and grip strength, were selected with reference to the content of the hydrotherapy programme as well as ease of administration (ie, time economic, patient familiarity) expertise and instrument availability. It was hypothesized that both active range of movement and grip strength would increase following hydrotherapy.

1. Active range of movement of wrist and knee flexion and extension was performed using a new standard universal goniometer (EMS, Wantage,Oxford) (Appendix 4.5) which displays 1° increments (thereby reducing error from end-digit bias). Measures were completed under standardized conditions which included no warm-up, standardized positioning of patient and standardized instructions according to the technique described by Norkin and White (1995). In order to maximize patient understanding of the task patients performed the required movement prior to testing. The widely used 0-180° notation system, in which the starting position is considered 0° and movements proceed toward 180° was adopted to record the results. These 2 joints were selected on the basis of the exercises performed, and relative ease and reliability of measurement [Brosseau et al., 2001; Gogia et al., 1987; Rothstein et al., 1983). Normal range of movement for flexion and extension for the knee is approximately 120 -140° and for the wrist approximately 130 - 150° (Miller, 1985). Expectation bias on the part of the examiner was minimized by concealing previous measures (Stratford et al., 1984).

2. Grip strength was included both as a functional and disease activity measure (Lee et al., 1974; Rhind et al., 1987) (Appendix 4.6). A digital grip strength monitor,

consisting of an inflatable bag attached to a manometer and with an accuracy of ± 3% was used (Mediscus Products Ltd). With the patient sitting (and feet on the floor with hips and knees in 90° of flexion) and the elbow, resting on a table, flexed to 90° and in the mid-prone position the patient gripped (power grip) the inflated (20mmHg) bag of the monitor "as hard as possible" for 3 seconds using the dominant hand. No visual feedback was permitted. The peak reading was recorded and the mean of 3 attempts was used in the analysis (Lee et al., 1974).

4.2.4b. Measures of Disease Activity

Three measures of disease activity (measures of inflammation) were selected to represent the different elements of this domain (Felson, 1993). Clinical measures included the Ritchie Index and the duration of morning stiffness (Appendices 4.7 and 4.8 respectively). The Ritchie Index was selected as a measure of joint tenderness and performed as described on pp 72-73 in Chapter 3 (Ritchie et al., 1968). Despite its questionable validity the duration of morning stiffness remains one the foundations in disease activity measures and has been reported in other studies of hydrotherapy. Therefore patients were asked to report their average duration of morning stiffness over the past 2 weeks. A laboratory measure, CRP, was selected to assess the impact of hydrotherapy on inflammation and to act as a surrogate marker for disease progression. Disease progression refers to radiological change. This study was of short duration and therefore X-ray measures of joint progression would have been inappropriate. As CRP levels are associated with slow radiological progression it was considered that this measure would provide a good and immediate marker of the effects of hydrotherapy on inflammatory activity (Devlin et al., 1997;

Otterness, 1994). At each assessment a 5ml sample of blood was drawn. Serum samples were frozen at -20°C within 2 hours of collection and subsequently tested in a single batch using a semi-automated latex method (Bayer RAXP). The coefficient of variation for this method is 0.04%. It was hypothesized that all measures of disease activity would reduce following hydrotherapy.

4.2.4c. Pain Measures

The experience of pain was measured in two ways. Firstly, patients completed the short-form McGill Pain Questionnaire and secondly, the Beliefs in Pain Control Questionnaire (Appendices 4.9, 4.10 and 4.11 respectively). The McGill Pain Questionnaire was selected on the basis of its psychometric properties and because it encompasses quantitative and qualitative aspects of pain. The short-form was selected because its content validity and ease of administration made it more suitable for use with RA patients (Skevington, 1979). A number of indices may be derived, but for this study the weighted values for each of the 3 dimensions was divided by the number of words chosen in that category, so a low number indicates mild pain and a high number severe pain (Charter and Nehemkis, 1983). It was hypothesized that effects of hydrotherapy would lessen the pain experienced by patients and be reflected in reduced McGill Pain Questionnaire scores.

The Beliefs in Pain Control Questionnaire was selected because beliefs in pain control may be important to pain experienced and may precede changes in pain symptoms (Skevington, 1990). Furthermore, hydrotherapy is promoted for its pain relief but the results from studies have shown disappointing results therefore including a measure which may prime improvements in reported pain was considered useful. It was hypothesized that the internal scale would be strengthened and/or the external scales weakened as result of hydrotherapy.

4.2.4d. Health Status Measures

The Arthritis Impact Measurement Scale (AIMS2) was selected because of its content, measurement properties and previous use in similar trials. It was anticipated that many of the patients in the study would be retired and/or their main form of work would be in the home. The work subscale of the AIMS2 was therefore adapted to differentiate between employment and housework by the addition of 4 questions in which 'paid work' was substituted by 'housework'. To ensure its suitability for use with a British patient population, the language and spelling used in the questionnaire were anglicised following the work by Hill et al. (1990), on the original instrument.

4.2.5. Statistical Methods

In this study we examined the hypothesis that hydrotherapy would increase measures of functional capacity significantly more, whilst those of pain, negative psychological mood and disease activity would decrease compared to the other interventions. There were 3 major aspects of the data analysis. Firstly, the data were screened for normality and checked for compliance with the assumptions of the tests selected. Next a factorial between-and-within subjects MANCOVA design with repeated measures and for unweighted means was used to compare the 4 groups over the 3 time periods and in relation to the covariates of disease duration, age and education. Finally, a two-group model was constructed whereby the effects of water based treatments (H and IMM) were compared to land treatments (LE and LR) and exercise interventions (H and LE) to non-exercise interventions (IMM and LR). Data was analysed using the Statistics Package for the Social Sciences.

4.2.5a. Data screening

Prior to the MANCOVA analyses the data was checked for compliance with the assumptions of this statistical test. Descriptive statistics on all dependent variables were checked for accuracy by examining plausible means, standard deviations and minimum and maximum values. Data normality was assessed by tests of univariate (skewness and kurtosis) and multivariate normality (Mahalanobis distance). Box plots were used to identify outliers, which were reassigned their previous score (Tabachnik and Fiddell, 1989). Measures of homoscedasticity (Bartlett–box test) were non-significant implying multivariate homogeneity. Marked skewness was a problem for some variables and these were transformed either by the log (grip strength) or the square root method (physical component scale of the AIMS2). Where appropriate, some variables were aggregated to provide conceptually viable composites and to accommodate abnormal distributions. The evaluative and affective scales of the McGill pain questionnaire were integrated, in line with previous research (Charter and Nehemkis, 1983). Also the physical variables of right and left knee range of movement and range of movement for the two wrists were summed (Bostrom et al., 1995). Distributions of the AIMS2 subscales tended to be abnormal, and so the five composite scales recommended by Meenan et al. (1992), were used as these exhibited relatively normal distributions. The physical component scale required square root transformation. Morning stiffness and CRP failed to satisfy the normality requirements for multivariate analysis and were therefore excluded from parametric analysis. These 2 variables were examined using the Kruskal-Wallis non-parametric test. A number of outliers were observed which were spaced between groups. For this reason and because of the MANCOVA assumption with regard to the number of cases per dependent variable outliers were retained but assigned the value from the previous testing session (Tabachnik and Fidell, 1989).

4.2.5c. Covariates

Covariates were chosen for their known association with the dependent variables. For example, age and disease duration have been shown to be negatively correlated with pain (Parker et al., 1988). Callahan et al. (1992), reported that low educational achievement was significantly correlated with poorer health outcome in RA and therefore education was included as a covariate. Income and occupation have also been advocated as covariates but as these variables correlated highly with education it was decided to use education as the covariate (Wolfe et al., 1999). Furthermore, occupation and income were significantly correlated with age. Disease duration and education were non-normally distributed as assessed by boxplots and measures of skewness and kurtosis and were therefore log transformed. Subsequent measures for assessing normality were satisfactory.

4.2.5d. MANCOVA Blocks

To satisfy MANCOVA assumptions about the number of cases in relation to the number of dependent variables, the dependent variables were divided into 3 groups of conceptually related measures for separate analysis (Tabachnik and Fidell, 1989). The first group considered the physical variables of Ritchie index, grip strength, wrist and knee range of movement; the second examined the pain variables from the McGill pain questionnaire and the Beliefs in Pain Control Questionnaire , and, the third consisted of the 5 composite health status scales from the AIMS2 questionnaire (Potts and Brandt, 1987). A second series of MANCOVAs was completed with the addition of sex as a factor to examine gender differences. Finally, in the third series of MANCOVAs environment (water versus no water) and activity (exercise versus no exercise) were examined for the 3 groups of conceptually related variables.

4.2.5e. Correlations

Pearson product moment correlations were completed for statistically significant findings.

4.6. RESULTS

4.6.1. Sample Characteristics

Of the 139 patients with chronic RA who completed the study, 96 were women and 43 were men. The mean age was 58.2 years (SD±11.1). Patients had a disease duration of 11.5 years (SD±8.7) and 66% were in functional class II indicating that, despite "handicap of discomfort or limited motion at one or more joints" patients are able to function adequately for normal activities (Hochberg et al., 1992). Table 4.2 details some of the demographic features. A oneway ANOVA or Kruskal-Wallis (gender and functional class) showed the groups to be comparable on these characteristics.

Table 4.2 – Characteristics of the 4 intervention groups. Age and disease duration are presented as mean (±SD).

Group	**Males: females**	**Age**	**Disease duration**	**Functional Class**		
				I	**II**	**III**
Hydrotherapy	14 : 21	55.8 (12.5)	9.7 (7.7)	9	21	5
Immersion	11 : 24	58.7 (11.3)	12.2 (9.2)	5	28	2
Land Exercise	8 : 26	58.5 (11)	11.9 (8.2)	3	24	7
Land Relaxation	10 :25	59.8 (9.3)	12.2 (9.6)	9	19	7

At the pre-test interview, 29.5% of patients reported one or more comorbidities on the AIMS2 questionnaire. These related in the main, to cardiorespiratory problems (eg, high blood pressure, asthma, angina). As these patients were evenly distributed throughout the intervention groups no attempt was made to control for comorbidity in the analysis.

At baseline 73% of patients were prescribed DMARDS and 83% NSAID; 5.8% were on oral steroids. The distribution of medication was similar between groups. Patients and their physicians were asked to maintain type and dose of pre-entry drugs as far as ethically possible during the study period. At each assessment patients were questioned on their current medication. Ninety-seven per cent of patients had been able to maintain pre-entry medication at post-test. By follow-up, this number had dropped to 79% and 12.2% required an intra-articular corticosteroid injection. Changes in drugs and requirements for intra-articular injections were evenly spread throughout the intervention groups.

Patient attendance for treatment was high overall with 92% of the sample attending at least 6 times and 56.8% attending all 8 sessions. Attendance between groups was similar as evaluated by the Kruskal-Wallis test (χ^2 =3.2, df=3, *P*=0.35).

4.6.2. Overall Results (n=139).

Overall, some measures changed in the direction of therapeutic improvement, independent of treatment allocation. Joint tenderness, as assessed by the Ritchie index, reduced significantly following treatment by 18% (from 21.15 to 17.3) (F=9.68, df=1,108; *P*=0.002). This remained significantly reduced at follow-up (F=15, df=1,113; *P* =0.001). At follow-up morning stiffness was significantly less than at baseline (z = -2.27, *P* =0.023). The combined evaluative affective score on the McGill Pain Questionnaire reduced significantly after treatment from 2.16 to 1.79 (F=8.2, df =1,119; *P* =0.005). These changes were not maintained at follow-up. All patients reported statistically significant pre- to post-test reductions in the belief that pain is controlled by chance happenings or misfortune (F=3.9, df=1,109; *P* =0.049) but this was not maintained at follow-up. The physical and affect scores on the AIMS2 questionnaire showed significant improvement at post-test (F= 7.6, df=1,115; *P* =0.007; F=9.3, df=1,113; *P* =0.003 respectively for physical capacity and affect).

Further improvement was observed at follow-up for these 2 variables (Physical capacity: $F=7.3$, $df=1,115$; $P=0.008$, Affect: $F=10.8$, $df=1,113$; $P=0.001$). Pain, as measured on the AIMS2 questionnaire increased significantly at follow-up ($F=4.01$, $df=1, 109$; $P=0.048$). Table 4.3 shows the overall significant and non-significant results. Analysis by gender showed that women experienced the greatest improvements in affect at post-test ($F=5.8$, $df=1,109$; $P=0.02$). Table 4.6 reports the significant findings for the effects of gender.

Table 4.3 – Significant and non-significant results for the total sample (n=139). Means and SD (in brackets) are presented except for morning stiffness and CRP (median and inter-quartile range). MPQ – McGill Pain Questionnaire. BPCQ – Beliefs in Pain Control Questionnaire. ROM –range of movement.

	Pre-test	Post-test	Follow-up
Statistically Significant Variables			
Ritchie Index	21.15 (9.7)	17.3 (9.4)*	18.1 (10.9) #
Morning stiffness (minutes)	30 (5-60)	20 (5-60)	15 (0-60)#
Evaluative/affective MPQ	2.16 (1.7)	1.8 (1.5)*	2.0 (1.8)
Chance happenings BPCQ	3.44 (0.9)	3.37 (0.9)*	3.3 (0.9)
Physical :AIMS2	2.54 (11.8)	2.37 (1.8)*	2.35 (1.8)*
Affect :AIMS2	3.3 (1.4)	3.0 (1.3)*	2.9 (1.3)*
Statistically Non-significant Variables			
Wrist ROM (°)	167.4 (60.3)	172.1 (59.9)	174.3 (58.8)
Knee ROM (°)	249.1 (25.6)	251.4 (26.4)	252.1 (24.1)
CRP	10.5 (10-25)	10 (10-20)	
Grip Strength (mmHG)	140.4 (75.6)	142.6 (75.5)	138.9 (70.6)
Sensory pain (MPQ)	2.48 (0.6)	2.59 (0.7)	2.45 (0.8)
Internal scale (BPCQ)	2.7 (0.8)	2.6 (0.8)	2.7 (0.8)
Powerful doctors (BPCQ)	3.8 (0.9)	3.89 (0.9)	3.96 (0.9)
Social (AIMS2)	3.4 (1.1)	3.52 (1.2)	3.54 (1.3)
Pain (AIMS2)	4.48 (2.2)	4.47 (2.2)	4.49 (2.3)
Work (AIMS2)	3.17 (2.3)	2.8 (2.2)	2.97 (2.3)

*significant improvement was observed between pre and post-test and post-test and follow-up (P <0.05). # significant improvement was observed between pre-test and follow-up (P <0.05).

4.6.3. Hydrotherapy Group Results

Whilst there was an overall reduction in joint tenderness after treatment patients in the hydrotherapy group had significantly lower Ritchie scores than other groups, with a mean decrease of 27% ($F=5.05$, $df=1,108$, $P=0.027$). Analysis by gender showed that women who received hydrotherapy had significantly increased their total combined knee range of movement by 6.6° by the end of the course ($F=3.98$, $df=1,98$, $P=0.049$) and although this improvement was maintained at follow-up, it was no longer statistically significant (Table 4.6). Whilst all patients improved their mood and tension, as assessed by the affect score on the AIMS2 questionnaire, patients in the hydrotherapy group demonstrated the greatest effect at follow-up ($F=4.6$, $df=1,112$, $P=0.03$). Tables 4.4 and 4.5 list the significant and non-significant findings for the hydrotherapy and other groups. Significant and positive correlations were noted between the Ritchie Index and pain, as measured on the AIMS2, at all time points ($r = 0.38 - 0.68$, $P<0.01$) and between the Ritchie index at post-test and affect at follow-up ($r = 0.63$, $P<0.001$).

4.6.4. Other Group Findings

In addition to the benefits accrued by all patients those in the IMM group had significantly less morning stiffness at follow-up compared to trial entry ($z=-2.15$, $P=0.03$). At study entry the median (and range) was 20 minutes (52.5) and at follow-up was 15 minutes (55).

Patients in the LE group had a significant reduction in joint tenderness at follow-up ($F=5.5$, $df=1,108$; $P=0.02$). Furthermore these patients reported significantly less pain, as measured on the AIMS2 between pre and post-test ($F=4.2$, $df=1,105$; $P=0.04$). This was not maintained at follow-up

Despite the overall finding that affective/evaluative pain decreased significantly in the sample between study entry and post-test the LR group actually experienced a 12.5% increase ($F=5.5$, $df=1,119$; $P=0.02$). Pain further increased by 43.7% at follow-up ($F=9.3$, $df=1,119$; $P=0.003$). Additionally beliefs that pain is controlled by chance happenings were found to have been strengthened in the LR group at follow-up ($F=6.1$, $df=1,113$; $P=0.01$).

CHAPTER 4

A RANDOMISED AND CONTROLLED TRIAL OF HYDROTHERAPY IN RA

4.1. INTRODUCTION

Chapter 2 discussed the use and rationale of hydrotherapy in patients with RA. It concluded that the scarce research available did not provide unequivocal evidence to support the claims made on behalf of hydrotherapy because the study designs were of poor quality. Given the lack of evidence of efficacy and its continuing popularity a well designed trial is overdue. Furthermore, speculation that the immersion component of hydrotherapy may contribute wholly or partially to the benefits claimed by patients with RA deserves scrutiny because this may have implications for treatment programmes. Therefore the present study was designed to test the hypothesis that the combined elements of water immersion and exercise in hydrotherapy were therapeutically superior to either evaluated singly. Therapeutic benefit was defined as improvement in measures of disease activity, physical and psychological function.

4.2. METHODS

Randomised controlled trials remain the gold standard in providing causal evidence with maximal internal validity (Grimes and Schulz, 2002). Evidence-based practice relies upon good quality systematic reviews and meta-analysis, both of which consider randomised clinical trial exclusively. Therefore the design employed to test the present hypothesis used a randomised clinical trial. Given the definition of hydrotherapy as a combination of 2 components and to test the hypothesis rigorously a 4 cell design was adopted. Therefore 3 control groups and one experimental group (hydrotherapy) were included. An exercise only (land exercise) and an immersion only (IMM) group enabled separation of the hydrotherapy components. Hydrotherapy and land exercise (LE) group sessions require direct supervision of the physiotherapist whereas seated immersion, in an earlier pilot study had taken the form of a social support group (Hall, 1993). Therefore, to equalize physiotherapy input and to prevent against self-exercise the IMM group performed a relaxation procedure in the water. A third control group was required to control for the effects of relaxation out of the water (Land Relaxation). Therefore 4 groups were convened in a between subjects factorial model (Table 4.1).

Table 4.1 - Patients were randomly allocated to one of 4 groups

	Hydrotherapy (H)	Immersion (IMM)	Land exercise (LE)	Land Relaxation (LR)
Water	+	+	-	-
Exercise	+	-	+	-
Relaxation	-	+	-	+

4.2.1. Subjects

The sample size was calculated from previous data collected in an earlier pilot study on the efficacy of hydrotherapy in patients with RA (Hall, 1993). The Ritchie index is a measure of joint tenderness and has been shown to correlate well with pain scores (Thompson et al., 1987). Furthermore, significant reduction of joint tenderness after hydrotherapy in 11 patients with RA was reported in the pilot study (Hall, 1993). Therefore, this measure was used to estimate sample size. The standardized difference for the Ritchie index was calculated by the mean pre- to post-difference divided by the standard deviation (5 ± 10.2) and with alpha set at 0.05 and power at 0.8. A nomogram showed that a sample size of 140 would be required (35 per group) [Altman, 1991].

Patients with RA who presented with functional classes I – III were included (Hochberg et al., 1992). To ensure entry of patients with chronic active RA only those with extensive disease as characterized by the involvement (ie, pain and tenderness) of at least 6 joints at pre-test were admitted. Study entry was also limited to those patients who were maintained on a stable drug regimen for a period of 30 days in the case of non-steroidal anti-inflammatories (NSAIDs) or 3 months for disease modifying antirheumatic drugs (DMARDS). Patients who had received intra-articular corticosteroid injections or physiotherapy treatment within 30 days of assessment for the study were excluded, as were patients who had joint replacement surgery within 6 months. Patients with a history of any known condition contraindicating exercise therapy or immersion in water (ie. recent myocardial infarction, resting angina, or fear of water) were also excluded, as were patients with uncontrolled pathology (eg, epilepsy) .

One hundred and forty-seven patients with RA who met the entry criteria were recruited to the study. Seven patients dropped out after 1-2 treatments and in accordance with the sample attrition policy were replaced. Reasons for dropping-out included transport difficulties, shortage of time, lack of interest and being allocated to an unwanted group. Drop-outs occurred mainly in the land relaxation (LR) group (n=5) and hydrotherapy group (n=2). Four patients, of which 3 (less than 10% of the group) were in the hydrotherapy group and one in the IMM group were withdrawn from treatment due to a flare up of their RA or a corticosteroid injection. The number of treatments given before withdrawal ranged from 1 – 5 and all patients completed a second assessment which was included in the statistical analysis. One patient withdrew following her 8 treatments of land exercise with a myocardial infarction and was therefore unable to attend for post-testing. Thus 139 patients completed the study with the land exercise group consisting of 34 patients.

4.2.2 Ethical Considerations

Ethical approval for this study was granted by the Bath District Research Ethics Committee.

4.2.3. Study and Treatment Protocol

Patients with RA, identified by their diagnoses from the database at the Royal National Hospital for Rheumatic Diseases, Bath, received a letter giving brief details of the study and inviting them to express interest by returning a tear-off slip in the SAE provided. Patients who responded positively received a telephone call from the researcher who explained the study protocol and, if appropriate asked some questions to establish the patients suitability (Appendix 4.1). Patients who met the initial entry criteria were invited to the hospital and following successful completion of the entry criteria and ethical permission forms were recruited to the study (Appendices 4.2 and 4.3). Pre-test measures were then completed.

Restricted random assignment following trial entry to one of the 4 groups was achieved by an independent co-ordinator using a random numbers table and groups of subjects in blocks so that equal numbers of subjects were allocated to each of the 4 groups (Grimes and Schultz, 2002; Kazdin, 1992). In this way the researcher remained "blind" to the treatment allocation. Patients were warned at every testing session not to reveal which treatment they had received.

All interventions took place in the gymnasium or hydrotherapy pool at the Royal National Hospital for Rheumatic Diseases, Bath. Patients were convened in small groups of 4 or 5. Three physiotherapists were trained to carry out the standardized exercise regimen and relaxation programmes. In accordance with standard therapeutic practice, the exercise sessions lasted for 30 minutes; the relaxation interventions were designed to last an equivalent length of time. Evidence from the pilot study suggested that 8 sessions of hydrotherapy (H) and land exercise (LE) would constitute a suitable course of treatment, and be in line with existing clinical practice. For reasons of patient fatigue, all interventions were limited to 2 sessions per week therefore patients attended for 4 consecutive weeks.

A generalized whole body exercise programme was designed for the H and LE groups with the broad aims of increasing peripheral joint range of movement and muscle strength of the upper and lower limbs (Appendix 4.4). The type of exercises and number of repetitions were standardized in consultation with the treating physiotherapists. The speed and resistance of each exercise was constantly monitored by the physiotherapist so that the patient was challenged at all times, as occurs in normal practice.

An adapted and updated version of Jacobsen's progressive relaxation technique (Jacobsen, 1938) including some mental imagery tasks, was tailored for use with arthritis patients in the two non-exercise groups (IMM and LR). Following training, the physiotherapist read from a relaxation script at each session. LR patients relaxed in a quiet darkened room on comfortable mats, or exercise couches, and with optional pillows supporting the head and knees. Patients in the IMM group relaxed in the pool whilst sitting with the legs dependent on weighted chairs. The water was maintained at the usual water temperature of 36°C and patients were immersed to the suprasternal notch.

Continuation of their treatment at home was not actively encouraged as it was recognized that transference of water-based exercises to land may have been difficult for the patient. However, if patients asked their physiotherapist if they should continue their treatment at home the physiotherapist agreed that this was possible. At both the post-test and follow-up assessments the researcher asked patients if they were practicing anything they had learnt from their treatment.

4.2.4. Assessments

Pre-, post test and 3 month follow-up assessments were completed by the researcher, who remained "blind" to the intervention. Patients were assessed on each occasion at the same time of day to control for diurnal variations in measurement and using the same order of testing (Bellamy et al., 1991; Harkness et al., 1982). The measures, detailed below, spanned physical function, disease activity, pain and self-report health status.

4.2.4a. Measures of Physical Function

Two measures of physical function, range of movement and grip strength, were selected with reference to the content of the hydrotherapy programme as well as ease of administration (ie, time economic, patient familiarity) expertise and instrument availability. It was hypothesized that both active range of movement and grip strength would increase following hydrotherapy.

1. Active range of movement of wrist and knee flexion and extension was performed using a new standard universal goniometer (EMS, Wantage,Oxford) (Appendix 4.5) which displays 1° increments (thereby reducing error from end-digit bias). Measures were completed under standardized conditions which included no warm-up, standardized positioning of patient and standardized instructions according to the technique described by Norkin and White (1995). In order to maximize patient understanding of the task patients performed the required movement prior to testing. The widely used 0-180° notation system, in which the starting position is considered 0° and movements proceed toward 180° was adopted to record the results. These 2 joints were selected on the basis of the exercises performed, and relative ease and reliability of measurement [Brosseau et al., 2001; Gogia et al., 1987; Rothstein et al., 1983). Normal range of movement for flexion and extension for the knee is approximately 120 -140° and for the wrist approximately 130 - 150° (Miller, 1985). Expectation bias on the part of the examiner was minimized by concealing previous measures (Stratford et al., 1984).

2. Grip strength was included both as a functional and disease activity measure (Lee et al., 1974; Rhind et al., 1987) (Appendix 4.6). A digital grip strength monitor,

consisting of an inflatable bag attached to a manometer and with an accuracy of ± 3% was used (Mediscus Products Ltd). With the patient sitting (and feet on the floor with hips and knees in 90° of flexion) and the elbow, resting on a table, flexed to 90° and in the mid-prone position the patient gripped (power grip) the inflated (20mmHg) bag of the monitor "as hard as possible" for 3 seconds using the dominant hand. No visual feedback was permitted. The peak reading was recorded and the mean of 3 attempts was used in the analysis (Lee et al., 1974).

4.2.4b. Measures of Disease Activity

Three measures of disease activity (measures of inflammation) were selected to represent the different elements of this domain (Felson, 1993). Clinical measures included the Ritchie Index and the duration of morning stiffness (Appendices 4.7 and 4.8 respectively). The Ritchie Index was selected as a measure of joint tenderness and performed as described on pp 72-73 in Chapter 3 (Ritchie et al., 1968). Despite its questionable validity the duration of morning stiffness remains one the foundations in disease activity measures and has been reported in other studies of hydrotherapy. Therefore patients were asked to report their average duration of morning stiffness over the past 2 weeks. A laboratory measure, CRP, was selected to assess the impact of hydrotherapy on inflammation and to act as a surrogate marker for disease progression. Disease progression refers to radiological change. This study was of short duration and therefore X-ray measures of joint progression would have been inappropriate. As CRP levels are associated with slow radiological progression it was considered that this measure would provide a good and immediate marker of the effects of hydrotherapy on inflammatory activity (Devlin et al., 1997;

Otterness, 1994). At each assessment a 5ml sample of blood was drawn. Serum samples were frozen at -20°C within 2 hours of collection and subsequently tested in a single batch using a semi-automated latex method (Bayer RAXP). The coefficient of variation for this method is 0.04%. It was hypothesized that all measures of disease activity would reduce following hydrotherapy.

4.2.4c. Pain Measures

The experience of pain was measured in two ways. Firstly, patients completed the short-form McGill Pain Questionnaire and secondly, the Beliefs in Pain Control Questionnaire (Appendices 4.9, 4.10 and 4.11 respectively). The McGill Pain Questionnaire was selected on the basis of its psychometric properties and because it encompasses quantitative and qualitative aspects of pain. The short-form was selected because its content validity and ease of administration made it more suitable for use with RA patients (Skevington, 1979). A number of indices may be derived, but for this study the weighted values for each of the 3 dimensions was divided by the number of words chosen in that category, so a low number indicates mild pain and a high number severe pain (Charter and Nehemkis, 1983). It was hypothesized that effects of hydrotherapy would lessen the pain experienced by patients and be reflected in reduced McGill Pain Questionnaire scores.

The Beliefs in Pain Control Questionnaire was selected because beliefs in pain control may be important to pain experienced and may precede changes in pain symptoms (Skevington, 1990). Furthermore, hydrotherapy is promoted for its pain relief but the results from studies have shown disappointing results therefore including a measure which may prime improvements in reported pain was considered useful. It was hypothesized that the internal scale would be strengthened and/or the external scales weakened as result of hydrotherapy.

4.2.4d. Health Status Measures

The Arthritis Impact Measurement Scale (AIMS2) was selected because of its content, measurement properties and previous use in similar trials. It was anticipated that many of the patients in the study would be retired and/or their main form of work would be in the home. The work subscale of the AIMS2 was therefore adapted to differentiate between employment and housework by the addition of 4 questions in which 'paid work' was substituted by 'housework'. To ensure its suitability for use with a British patient population, the language and spelling used in the questionnaire were anglicised following the work by Hill et al. (1990), on the original instrument.

4.2.5. Statistical Methods

In this study we examined the hypothesis that hydrotherapy would increase measures of functional capacity significantly more, whilst those of pain, negative psychological mood and disease activity would decrease compared to the other interventions. There were 3 major aspects of the data analysis. Firstly, the data were screened for normality and checked for compliance with the assumptions of the tests selected. Next a factorial between-and-within subjects MANCOVA design with repeated measures and for unweighted means was used to compare the 4 groups over the 3 time periods and in relation to the covariates of disease duration, age and education. Finally, a two-group model was constructed whereby the effects of water based treatments (H and IMM) were compared to land treatments (LE and LR) and exercise interventions (H and LE) to non-exercise interventions (IMM and LR). Data was analysed using the Statistics Package for the Social Sciences.

4.2.5a. Data screening

Prior to the MANCOVA analyses the data was checked for compliance with the assumptions of this statistical test. Descriptive statistics on all dependent variables were checked for accuracy by examining plausible means, standard deviations and minimum and maximum values. Data normality was assessed by tests of univariate (skewness and kurtosis) and multivariate normality (Mahalanobis distance). Box plots were used to identify outliers, which were reassigned their previous score (Tabachnik and Fiddell, 1989). Measures of homoscedasticity (Bartlett–box test) were non-significant implying multivariate homogeneity. Marked skewness was a problem for some variables and these were transformed either by the log (grip strength) or the square root method (physical component scale of the AIMS2). Where appropriate, some variables were aggregated to provide conceptually viable composites and to accommodate abnormal distributions. The evaluative and affective scales of the McGill pain questionnaire were integrated, in line with previous research (Charter and Nehemkis, 1983). Also the physical variables of right and left knee range of movement and range of movement for the two wrists were summed (Bostrom et al., 1995). Distributions of the AIMS2 subscales tended to be abnormal, and so the five composite scales recommended by Meenan et al. (1992), were used as these exhibited relatively normal distributions. The physical component scale required square root transformation. Morning stiffness and CRP failed to satisfy the normality requirements for multivariate analysis and were therefore excluded from parametric analysis. These 2 variables were examined using the Kruskal-Wallis non-parametric test. A number of outliers were observed which were spaced between groups. For this reason and because of the MANCOVA assumption with regard to the number of cases per dependent variable outliers were retained but assigned the value from the previous testing session (Tabachnik and Fidell, 1989).

4.2.5c. Covariates

Covariates were chosen for their known association with the dependent variables. For example, age and disease duration have been shown to be negatively correlated with pain (Parker et al., 1988). Callahan et al. (1992), reported that low educational achievement was significantly correlated with poorer health outcome in RA and therefore education was included as a covariate. Income and occupation have also been advocated as covariates but as these variables correlated highly with education it was decided to use education as the covariate (Wolfe et al., 1999). Furthermore, occupation and income were significantly correlated with age. Disease duration and education were non-normally distributed as assessed by boxplots and measures of skewness and kurtosis and were therefore log transformed. Subsequent measures for assessing normality were satisfactory.

4.2.5d. MANCOVA Blocks

To satisfy MANCOVA assumptions about the number of cases in relation to the number of dependent variables, the dependent variables were divided into 3 groups of conceptually related measures for separate analysis (Tabachnik and Fidell, 1989). The first group considered the physical variables of Ritchie index, grip strength, wrist and knee range of movement; the second examined the pain variables from the McGill pain questionnaire and the Beliefs in Pain Control Questionnaire , and, the third consisted of the 5 composite health status scales from the AIMS2 questionnaire (Potts and Brandt, 1987). A second series of MANCOVAs was completed with the addition of sex as a factor to examine gender differences. Finally, in the third series of MANCOVAs environment (water versus no water) and activity (exercise versus no exercise) were examined for the 3 groups of conceptually related variables.

4.2.5e. Correlations

Pearson product moment correlations were completed for statistically significant findings.

4.6. RESULTS

4.6.1. Sample Characteristics

Of the 139 patients with chronic RA who completed the study, 96 were women and 43 were men. The mean age was 58.2 years (SD±11.1). Patients had a disease duration of 11.5 years (SD±8.7) and 66% were in functional class II indicating that, despite "handicap of discomfort or limited motion at one or more joints" patients are able to function adequately for normal activities (Hochberg et al., 1992). Table 4.2 details some of the demographic features. A oneway ANOVA or Kruskal-Wallis (gender and functional class) showed the groups to be comparable on these characteristics.

Table 4.2 – Characteristics of the 4 intervention groups. Age and disease duration are presented as mean (±SD).

Group	**Males: females**	**Age**	**Disease duration**	**Functional Class**		
				I	**II**	**III**
Hydrotherapy	14 : 21	55.8 (12.5)	9.7 (7.7)	9	21	5
Immersion	11 : 24	58.7 (11.3)	12.2 (9.2)	5	28	2
Land Exercise	8 : 26	58.5 (11)	11.9 (8.2)	3	24	7
Land Relaxation	10 :25	59.8 (9.3)	12.2 (9.6)	9	19	7

At the pre-test interview, 29.5% of patients reported one or more comorbidities on the AIMS2 questionnaire. These related in the main, to cardiorespiratory problems (eg, high blood pressure, asthma, angina). As these patients were evenly distributed throughout the intervention groups no attempt was made to control for comorbidity in the analysis.

At baseline 73% of patients were prescribed DMARDS and 83% NSAID; 5.8% were on oral steroids. The distribution of medication was similar between groups. Patients and their physicians were asked to maintain type and dose of pre-entry drugs as far as ethically possible during the study period. At each assessment patients were questioned on their current medication. Ninety-seven per cent of patients had been able to maintain pre-entry medication at post-test. By follow-up, this number had dropped to 79% and 12.2% required an intra-articular corticosteroid injection. Changes in drugs and requirements for intra-articular injections were evenly spread throughout the intervention groups.

Patient attendance for treatment was high overall with 92% of the sample attending at least 6 times and 56.8% attending all 8 sessions. Attendance between groups was similar as evaluated by the Kruskal-Wallis test (χ^2 =3.2, df=3, P=0.35).

4.6.2. Overall Results (n=139).

Overall, some measures changed in the direction of therapeutic improvement, independent of treatment allocation. Joint tenderness, as assessed by the Ritchie index, reduced significantly following treatment by 18% (from 21.15 to 17.3) (F=9.68, df=1,108; P=0.002). This remained significantly reduced at follow-up (F=15, df=1,113; P =0.001). At follow-up morning stiffness was significantly less than at baseline (z = -2.27, P =0.023). The combined evaluative affective score on the McGill Pain Questionnaire reduced significantly after treatment from 2.16 to 1.79 (F=8.2, df =1,119; P =0.005). These changes were not maintained at follow-up. All patients reported statistically significant pre- to post-test reductions in the belief that pain is controlled by chance happenings or misfortune (F=3.9, df=1,109; P =0.049) but this was not maintained at follow-up. The physical and affect scores on the AIMS2 questionnaire showed significant improvement at post-test (F= 7.6, df=1,115; P =0.007; F=9.3, df=1,113; P =0.003 respectively for physical capacity and affect).

Further improvement was observed at follow-up for these 2 variables (Physical capacity: $F=7.3$, $df=1,115$; $P=0.008$, Affect: $F=10.8$, $df=1,113$; $P=0.001$). Pain, as measured on the AIMS2 questionnaire increased significantly at follow-up ($F=4.01$, $df=1, 109$; $P=0.048$). Table 4.3 shows the overall significant and non-significant results. Analysis by gender showed that women experienced the greatest improvements in affect at post-test ($F=5.8$, $df=1,109$; $P=0.02$). Table 4.6 reports the significant findings for the effects of gender.

Table 4.3 – Significant and non-significant results for the total sample (n=139). Means and SD (in brackets) are presented except for morning stiffness and CRP (median and inter-quartile range). MPQ – McGill Pain Questionnaire. BPCQ – Beliefs in Pain Control Questionnaire. ROM –range of movement.

	Pre-test	Post-test	Follow-up
Statistically Significant Variables			
Ritchie Index	21.15 (9.7)	17.3 (9.4)*	18.1 (10.9) #
Morning stiffness (minutes)	30 (5-60)	20 (5-60)	15 (0-60)#
Evaluative/affective MPQ	2.16 (1.7)	1.8 (1.5)*	2.0 (1.8)
Chance happenings BPCQ	3.44 (0.9)	3.37 (0.9)*	3.3 (0.9)
Physical :AIMS2	2.54 (11.8)	2.37 (1.8)*	2.35 (1.8)*
Affect :AIMS2	3.3 (1.4)	3.0 (1.3)*	2.9 (1.3)*
Statistically Non-significant Variables			
Wrist ROM (°)	167.4 (60.3)	172.1 (59.9)	174.3 (58.8)
Knee ROM (°)	249.1 (25.6)	251.4 (26.4)	252.1 (24.1)
CRP	10.5 (10-25)	10 (10-20)	
Grip Strength (mmHG)	140.4 (75.6)	142.6 (75.5)	138.9 (70.6)
Sensory pain (MPQ)	2.48 (0.6)	2.59 (0.7)	2.45 (0.8)
Internal scale (BPCQ)	2.7 (0.8)	2.6 (0.8)	2.7 (0.8)
Powerful doctors (BPCQ)	3.8 (0.9)	3.89 (0.9)	3.96 (0.9)
Social (AIMS2)	3.4 (1.1)	3.52 (1.2)	3.54 (1.3)
Pain (AIMS2)	4.48 (2.2)	4.47 (2.2)	4.49 (2.3)
Work (AIMS2)	3.17 (2.3)	2.8 (2.2)	2.97 (2.3)

*significant improvement was observed between pre and post-test and post-test and follow-up (P <0.05). # significant improvement was observed between pre-test and follow-up (P <0.05).

4.6.3. Hydrotherapy Group Results

Whilst there was an overall reduction in joint tenderness after treatment patients in the hydrotherapy group had significantly lower Ritchie scores than other groups, with a mean decrease of 27% ($F=5.05$, $df=1,108$, $P=0.027$). Analysis by gender showed that women who received hydrotherapy had significantly increased their total combined knee range of movement by 6.6° by the end of the course ($F=3.98$, $df=1,98$, $P=0.049$) and although this improvement was maintained at follow-up, it was no longer statistically significant (Table 4.6). Whilst all patients improved their mood and tension, as assessed by the affect score on the AIMS2 questionnaire, patients in the hydrotherapy group demonstrated the greatest effect at follow-up ($F=4.6$, $df=1,112$, $P=0.03$). Tables 4.4 and 4.5 list the significant and non-significant findings for the hydrotherapy and other groups. Significant and positive correlations were noted between the Ritchie Index and pain, as measured on the AIMS2, at all time points ($r = 0.38 - 0.68$, $P<0.01$) and between the Ritchie index at post-test and affect at follow-up ($r = 0.63$, $P<0.001$).

4.6.4. Other Group Findings

In addition to the benefits accrued by all patients those in the IMM group had significantly less morning stiffness at follow-up compared to trial entry ($z=-2.15$, $P=0.03$). At study entry the median (and range) was 20 minutes (52.5) and at follow-up was 15 minutes (55).

Patients in the LE group had a significant reduction in joint tenderness at follow-up ($F=5.5$, $df=1,108$; $P=0.02$). Furthermore these patients reported significantly less pain, as measured on the AIMS2 between pre and post-test ($F=4.2$, $df=1,105$; $P=0.04$). This was not maintained at follow-up

Despite the overall finding that affective/evaluative pain decreased significantly in the sample between study entry and post-test the LR group actually experienced a 12.5% increase ($F=5.5$, $df=1,119$; $P=0.02$). Pain further increased by 43.7% at follow-up ($F=9.3$, $df=1,119$; $P=0.003$). Additionally beliefs that pain is controlled by chance happenings were found to have been strengthened in the LR group at follow-up ($F=6.1$, $df=1,113$; $P=0.01$).

Table 4.4 - Statistically significant findings for the hydrotherapy and other groups. Means and SD (in brackets) are presented except for morning stiffness (median and range). AIMS2- Arthritis Impact Measurement Scale. MPQ – McGill Pain Questionnaire. BPCQ – Beliefs in Pain Control Questionnaire.

	Hydrotherapy			**Immersion**			**Land exercise**			**Land relaxation**		
	Pre	**Post**	**F-up**	**Pre**	**Post**	**F-up**	**Pre**	**Post**	**F-up**	**Pre**	**Post**	**F-up**
Ritchie Index	21.3 (10.6)	15.5* (9.4)	17.9 (12.8)	19.9 (8.9)	16.8 (9.7)	18.2 (9.3)	21.8 (10.5)	18.9 (9.2)	16.6# (9.7)	21.4 (9.1)	18.1 (9.6)	19.5 (11.2)
Morning stiffness (minutes)	30 (55)	30 (55)	15 (40)	20 (52.5)	15 (56)	15^ (55)	12.5 (43.7)	10 (58)	10 (33.75)	30 (72.5)	30 (55)	30 (57.5)
Evaluative/affective Pain (MPQ)	2.63 (1.7)	2.1 (1.8)	2.06 (1.8)	2.4 (1.9)	1.9 (1.6)	2.06 (1.7)	2.1 (1.6)	1.3 (1.2)	1.7 (1.6)	1.6 (1.5)	1.8= (1.4)	2.3= (2)
Chance Happenings (BPCQ)	3.46 (1)	3.47 (0.8)	3.4 (0.9)	3.5 (0.8)	3.3 (0.8)	3.2 (0.7)	3.4 (0.9)	3.2 (0.8)	3.1 (0.8)	3.5 (0.9)	3.5 (0.9)	3.6== (1)
Affect (AIMS2)	3.5 (1.4)	3.3 (1.6)	3 ** (1.5)	3.2 (1.2)	2.9 (1.2)	3 (1.2)	3.2 (1.5)	2.8 (1.3)	2.7 (1.4)	3.3 (1.4)	2.9 (1.3)	3.2 (1.2)
Pain (AIMS2)	4.9 (2.2)	4.8 (2.7)	4.8 (2.5)	4.3 (2.2)	4.3 (2.2)	4.5 (2.4)	4.1 (1.9)	3.8## (1.8)	3.8 (1.9)	4.5 (1.9)	4.8 (1.9)	4.7 (2.2)

Table 4.4 – continued

Hydrotherapy

*The Ritchie Index was significantly reduced at post-test (F=5.05, df=1,108; *P*=0.027).

**The affect score was significantly less at follow-up (F=4.6, df= 1,112; *P*=0.03).

Immersion

^Morning stiffness was significantly reduced at follow-up (z= -2.15, *P*=0.03).

Land Exercise

#The Ritchie Index was significantly reduced at follow-up (F=5.5, df=1,108; *P*=0.02).

Pain (AIMS2) was significantly less at post-test (F=4.2, df =1,105; *P* =0.04).

Land Relaxation

=Evaluative/affective pain (MPQ) increased at post-test and follow-up(F= 5.5, df=1,119; *P*=0.02 and F=9.3, df=1,119; *P*=0.003).

==Beliefs in chance happenings (BPCQ) were strengthened at follow-up up (F= 6.1, df=1,113; *P*=0.01).

Table 4.5 - Statistically non-significant findings for the hydrotherapy and other groups. Means and SD (in brackets) are presented except for C-reactive protein which was measured at pre-and post-test only (median and range). ROM – range of movement. AIMS2 - Arthritis Impact Measurement Scale. MPQ – McGill Pain Questionnaire. BPCQ – Beliefs in Pain Control Questionnaire. NB – ranges of movement are presented as summed (ie, right and left) variables.

	Hydrotherapy			**Immersion**			**Land exercise**			**Land relaxation**		
	Pre	**Post**	**F-up**	**Pre**	**Post**	**F-up**	**Pre**	**Post**	**F-up**	**Pre**	**Post**	**F-up**
Knee ROM (degrees)	248.4 (25.9)	252.4 (27)	252.2 (23.5)	248.1 (27.4)	252.3 (25.7)	254.9 (26.3)	250.8 (25.9)	248.7 (28.1)	248.8 (25.7)	249 (24.6)	251.9 (28.5)	252.8 (21.7)
Wrist ROM (degrees)	178.5 (54.7)	181.8 (55)	186.8 (54.5)	170.9 (56.2)	179.9 (59.6)	176.7 (63.9)	161.2 (68)	166.8 (60.9)	171.3 (59.25)	158.3 (62.5)	159.6 (64.2)	161.9 (58.4)
Grip Strength (mmHg)	148.5 (77.5)	152.5 (77.9)	152.2 (70.5)	134.8 (62.5)	141.7 (60.5)	126.6 (50.3)	143.9 (92)	142 (99)	137.9 (91.9)	137.5 (71.1)	134.2 (61.5)	137.3 (63.3)

Table 4.5 - continued

	Hydrotherapy			Immersion			Land exercise			Land relaxation		
	Pre	**Post**	**F-up**	**Pre**	**Post**	**F-up**	**Pre**	**Post**	**F-up**	**Pre**	**Post**	**F-up**
C-reactive protein (mg/l)	10 (10)	10 (10)		11 (15.5)	11 (6)		15 (17.5)	10 (24)		10 (18)	10 (21)	
Sensory Pain (MPQ)	2.55 (0.6)	2.64 (0.7)	2.46 (0.8)	2.4 (0.6)	2.7 (0.7)	2.45 (0.8)	2.53 (0.6)	2.57 (0.7)	2.5 (0.7)	2.4 (0.7)	2.4 (0.6)	2.4 (0.8)
Internal scale (BPCQ)	2.6 (0.8)	2.74 (0.7)	2.8 (0.7)	2.8 (0.8)	2.75 (0.9)	2.7 (0.8)	2.6 (0.8)	2.5 (0.7)	2.6 (0.8)	2.8 (0.8)	2.6 (0.8)	2.6 (0.7)
Powerful doctors (BPCQ)	3.9 (1.2)	3.85 (1.1)	3.87 (1.1)	3.9 (0.8)	3.9 (0.9)	4.06 (0.8)	3.7 (0.9)	3.8 (1)	3.75 (0.9)	3.87 (0.8)	3.96 (0.9)	4.1 (0.8)
Social (AIMS2)	3.6 (1.2)	3.5 (1.3)	3.6 (1.3)	3.4 (1.2)	3.4 (1.2)	3.5 (1.2)	3.38 (1.2)	3.5 (1.3)	3.4 (1.4)	3.39 (1)	3.5 (1.1)	3.6 (1.1)
Work (AIMS2)	3.05 (1.9)	2.4 (1.9)	2.8 (2.5)	2.79 (2.3)	2.8 (2.3)	2.5 (2.1)	3.09 (2.8)	3.1 (2.3)	3.3 (2.7)	3.1 (2.2)	2.9 (2.2)	3.2 (2)

Table 4.6 - Statistically significant gender effects (means and standard deviations).

	Overall (n=139)			**Hydrotherapy (n=35)**			**Immersion (n=35)**			**Land Exercise (n=34)**			**Land Relaxation (n=35)**		
	Pre	**Post**	**Follow-up**	**Pre**	**Post**	**Follow-up**	**Pre**	**Post**	**Follow-up**	**Pre**	**Post**	**Follow-up**	**Pre**	**Post**	**Follow-up**
Knee Range of Movement (degrees)															
Men	245.4 (26.8)	249.2 (28.2)	248.1 (24.6)	244.8 (23.9)	245.2 (24.3)	243.6 (23.4)	235.4 (35.4)	243.4 (34.4)	243.8 (31.3)	254.8 (27.8)	256.3 (28.1)	253.7 (24.4)	246.6 (20.3)	252 (26)	251.7 (19.5)
Women	250.7 (25.8)	252.6 (26.3)	254.1 (24)	250.7 (27.6)	257.3* (28.3)	257.9 (22.4)	252.5 (23.4)	255.3 (22.2)	258.7 (24.1)	249.4 (25.8)	246.1 (28.3)	247.1 (26.6)	249.9 (26.5)	251.9 (26.4)	252.7 (23)
Affect (AIMS2)															
Men	2.87 (1.5)	2.89 (1.5)	2.85 (1.2)	3.5 (1.5)	3.5 (1.8)	2.98 (1.6)	2.9 (1.8)	2.8 (1.5)	2.9 (1.4)	1.9 (1.5)	2.2 (1.4)	2.2 (1.1)	3.2 (1.4)	3 (1.6)	3.37 (0.8)
Women	3.5 (1.3)	3.04# (1.3)	3 (1.3)	3.6 (1.4)	3.2 (1.5)	3 (1.5)	3.4 1.1)	3 (1)	3.1 (1.1)	3.5 (1.4)	3 (1.3)	2.9 (1.5)	3.3 (1.5)	2.9 (1.2)	3.1 (1.3)

* Women having hydrotherapy significantly increased knee range of movement between pre and post-test (F=3.98, df=1,98; P=0.049).

At post-test women reported the greatest improvement in affect scores (F=5.8, df=1,109; P=0.02).

4.6.5. The two-group model

Table 4.7 shows that no differences were observed between the water-based groups and land-based groups on any of the outcome variables. Table 4.8 shows that exercising patients reported a small but significant reduction in the levels of pain (AIMS2) at post-test ($F=4.3$, $df=1,109$; $P=0.04$). At follow-up patients receiving exercise had improved affect scores on the AIMS2 questionnaire than those allocated to non-exercise groups ($F=4.7$, $df=1,112$; $P=0.03$).

Table 4.7 –Effects of Environment. Means and SD for each variable for the 2-group model (water and land) are presented. Morning stiffness is presented as the median and range. No significant differences were noted. ROM –range of movement. MPQ – McGill Pain Questionnaire.

	Water			**Land**		
	Pre-test	**Post-test**	**Follow-up**	**Pre-test**	**Post-test**	**Follow-up**
Physical Variables						
Ritchie Index	20.7 (9.8)	16.86 (9.63)	18.3 (11.3)	21.28 (10)	18.55 (9.7)	17.7 (10.7)
Morning Stiffness (minutes)	25 (53.7)	15 (55)	15 (51.25)	30 (55)	20 (55)	20 (60)
Grip strength (mmHg)	140.3 (70)	147 (69.5)	142.5 (60.5)	140.6 (81.4)	138 (81.4)	137.6 (78)
Wrist ROM (°)	176.5 (55.5)	181.9 (57.7)	181.3 (58)	164.9 (67)	167 (63)	166.7 (58.7)
Knee ROM (°)	243 (31.7)	248 (29.6)	249.8 (29.4)	247.9 (28)	247.6 (32)	247.4 (28.5)
Pain Variables						
Sensory pain (MPQ)	2.46 (0.6)	2.66 (0.75)	2.44 (0.8)	2.5 (0.6)	2.49 (0.6)	2.41 (0.8)
Evaluative/affective (MPQ)	2.54 (1.8)	2.1 (1.8)	2.06 (1.8)	1.89 (1.5)	1.62 (1.4)	1.96 (1.8)

Table 4.7 - continued

	Water			Land		
	Pre-test	**Post-test**	**Follow-up**	**Pre-test**	**Post-test**	**Follow-up**
Internal Scale (BPCQ)	2.84 (0.9)	2.8 (0.9)	2.86 (0.8)	2.72 (0.8)	2.62 (0.8)	2.66 (0.8)
Powerful Doctors (BPCQ)	3.88 (1)	3.9 (1)	3.97 (1)	3.78 (0.9)	3.88 (0.9)	3.95 (0.9)
Chance Happenings (BPCQ)	3.43 (1)	3.34 (0.9)	3.24 (0.9)	3.42 (0.9)	3.35 (0.9)	3.39 (0.9)
AIMS2 variables						
Physical (AIMS2)	2.28 (1.6)	2.15 (1.8)	2 (1.6)	2.81 (1.9)	2.6 (1.9)	2.66 (1.9)
Affect (AIMS2)	3.4 (1.4)	3.2 (1.5)	3.08 (1.4)	3.31 (1.4)	2.93 (1.2)	3.1 (1.3)
Social (AIMS2)	3.48 (1)	3.43 (1.2)	3.5 (1.3)	3.41 (1)	3.6 (1)	3.5 (1)
Pain (AIMS2)	4.8 (2.2)	4.7 (2.4)	4.8 (2.4)	4.42 (1.9)	4.38 (1.8)	4.39 (2)
Work (AIMS2)	3.1 (2)	2.97 (2.4)	2.77 (2.3)	3.37 (2.5)	3.13 (2.3)	3.3 (2.4)

Table 4.8 –Effects of Activity. Means and SD for each variable for the 2-group model (exercise and no exercise) are presented. Morning stiffness is presented as the median and range. ROM - range of movement.

	Exercise			**No Exercise**		
	Pre-test	**Post-test**	**Follow-up**	**Pre-test**	**Post-test**	**Follow-up**
Statistically Significant Variables						
Affect (AIMS2)	3.4 (1.4)	3.1 (1.5)	3 (1.5)*	3.32 (1.4)	3 (1.3)	3.2 (1.2)
Pain (AIMS2)	4.7 (2.1)	4.5 (2.3)*	4.5 (2.2)	4.6 (2)	4.6 (2)	4.7 (2.2)
Statistically Non-significant Variables						
Ritchie Index	21.2 (10.5)	17.49 (9.4)	17.3 (10.9)	20.8 (9.4)	17.9 (9.9)	18.8 (11)
Morning Stiffness (minutes)	17.5 (55)	15 (55.75)	12.5 (45)	30 (55)	20 (55)	30 (55)
Grip strength (mmHg)	144.9 (84)	147 (88)	147.5 (79)	136 (66.4)	137.9 (60.7)	132.2 (57)
Wrist ROM (°)	168.8 (63.7)	173.9 (61.4)	176.7 (57)	172.7 (60)	175.3 (60.7)	170.8 (60.7)
Knee ROM (°)	244.7 (32)	246.5 (32)	246.4 (29.7)	246.2 (28)	249.3 (29)	250.9 (28)
Sensory pain (MPQ)	2.55 (0.6)	2.6 (0.7)	2.44 (0.8)	2.41 (0.6)	2.54 (0.7)	2.41 (0.8)

Table 4.8 - continued

	Exercise			No Exercise		
	Pre-test	**Post-test**	**Follow-up**	**Pre-test**	**Post-test**	**Follow-up**
Evaluative/affective (MPQ)	2.38 (1.6)	1.7 (1.7)	1.8 (1.7)	2.05 (1.8)	2 (1.6)	2.3 (1.9)
Internal Scale (BPCQ)	2.7 (0.8)	2.7 (0.8)	2.8 (0.8)	2.84 (0.9)	2.71 (0.9)	2.72 (0.8)
Powerful Doctors (BPCQ)	3.7 (1)	3.8 (1)	3.8 (1)	3.94 (0.8)	3.98 (0.9)	4.13 (0.9)
Chance Happenings (BPCQ)	3.4 (1)	3.3 (0.9)	3.2 (0.9)	3.46 (0.9)	3.38 (0.9)	3.41 (0.9)
Physical (AIMS2)	2.5 (1.9)	2.37 (2)	2.3 (2)	2.59 (1.6)	2.4 (1.7)	2.4 (1.7)
Social (AIMS2)	3.5 (1)	3.58 (1.4)	3.45 (1.4)	3.38 (1)	3.45 (1)	3.57 (1)
Work (AIMS2)	3.4 (2.4)	3 (2.3)	3 (2.5)	3.06 (2.2)	3.1 (2.4)	2.98 (2.1)

* Exercising patients had significantly reduced pain (AIMS2) at post-test (P=0.04) and improved affect scores (AIMS2) at follow-up (P=0.03).

4.7. DISCUSSION

In addition to the physical and psychological benefits of placebo attention seen in all the intervention groups, hydrotherapy patients demonstrated value added benefits for the physical and emotional aspects of rheumatoid arthritis. The results suggest an enhancement effect in the interaction between exercise and the water, with minor emphasis on the former.

While all groups improved their joint tenderness over the 4 weeks, the hydrotherapy group experienced superior relief. This confirms reports by previous investigators who noted improvement in clinically active joints after a pool programme which was not evident in the land based group (Minor et al., 1989). Furthermore land based exercise studies have failed to note improvements in joint tenderness although it should be noted that at follow-up the Ritchie Index was reduced in the land exercise group (Van den Ende et al., 2000 and 1996; Westby et al., 2000; Komatireddy et al., 1997). Therefore it is likely that the properties of the water, and in particular the unloading effect of buoyancy are important in reducing joint tenderness. (Nakazawa et al., 1994; Harrison and Bulstrode, 1987). Furthermore, given that joint tenderness and pain may be similar constructs (Thompson and Kirwan, 1995; Gaston-Johansson and Gustafasson, 1990) it seems plausible, within the terms of current theory about pain, that the warmth of the water facilitates a closure of the 'gate' in the spinal cord, and in enhancing the blood flow, relieves the pain (Melzack and Wall, 1988). Significant and positive correlations between the Ritchie Index and pain, as measured on the AIMS2 questionnaire at all time points confirm previous reports of the relationship between these two variables but the pain relieving properties of hydrotherapy appear elusive. Patients having hydrotherapy did not experience the hypothesized greater pain relief, despite their reduction in joint tenderness. Similar findings have been reported by others (Stenstrom et al., 1991; Minor et al., 1989). In fact, there is little in the literature to suggest that hydrotherapy provokes sustained pain relief, despite patient and therapist conviction for such an effect. It may be that exercising in water provides temporal pain relief that allows greater capacity for exercise than on land and therefore measuring pain during comparable exercise programmes may be useful. Given the considerable body of theory supporting the use of water as an analgesic agent and clinician and patient expectation further research is warranted. The role of exercise in reducing pain may be surmised by the fact that it was only the land exercise patients who experienced a significant reduction in their pain as measured on the AIMS2 questionnaire. Evidence for pain relief following exercise on land suggests that pain intensity, as measured by a visual analogue scale, is reduced (van den Ende et al., 2000; Hakkinen et al., 1999b; Komatireddy et al., 1997). The central importance of exercise to the relief of pain was observed in the significant reduction of pain (as measured on the AIMS2) when the exercising groups were combined in the analysis. Therefore increasing the intensity of exercise within hydrotherapy may elicit the expected analgesia. Furthermore, evaluative/affective pain worsened in the Land Relaxation group and this strengthens the argument for the benefits of dynamic exercise in reducing pain.

Other measures of disease activity, including grip strength, morning stiffness and CRP did not change following hydrotherapy suggesting that this treatment does not exacerbate the inflammatory response. Whilst it is impossible to isolate any differences to the RA patients undergoing hydrotherapy in Minor's (1989) study it is interesting to note that this group had significant improvements in grip strength and duration of morning stiffness. The characteristics of this group in terms of age, sex and baseline variables were similar to the present study and therefore it may be that differences in the intervention account for the disparity in results. Minor's group exercised for 1 hour three times per week for 12 weeks compared to the 30 minutes twice a week for 4 weeks. Therefore a longer period of pool exercise may have resulted in improvements in more clinical disease activity measures.

Despite the failure of hydrotherapy to reduce morning stiffness immersion per se was noted to reduce this variable and whilst this appears to occur at post-test is not statistically significant until follow-up. The phenomenon of morning stiffness is incompletely understood but Scott (1960) suggested that it is related to an increase in inflammatory oedema in the early morning (secondary to diurnal variation in adrenal corticosteroid production) and patients, in a qualitative study, associated stiffness with swelling (Lineker et al., 1999). Epstein (1978) showed no change in glucocorticoids in normals during head-out water immersion and given the known effects of hydrostatic pressure on capillary mechanics it is likely that oedema would be reduced thereby ameliorating joint stiffness (Hall, 1993; Grahame et al., 1978). Sukenik et al (1990a and 1990b) found similar reductions in duration of morning stiffness after immersion which he attributed to the high salt concentration of the water (Dead Sea water) and buoyancy. If stiffness is associated with muscle tension then the buoyancy of the water would aid in its reduction via the reduction of tone as evidenced by bioelectrical silence (Kelly et al., 2000; Sugajima et al., 1996; Mitarai et al., 1972).

Reducing joint stiffness may be expected to increase joint motion and an increase in knee range of movement was observed for women undergoing hydrotherapy. This finding must be viewed with caution, despite adjustment for unequal numbers in the analysis, due to the small numbers of men in the sample (n=14). Improved range of motion may be related to the severity of oedema at admission to the trial. Due to the unreliability of available measures knee swelling was not assessed and it is therefore unknown whether women presented with greater oedema than men and hence greater capacity for improvement. The clinical significance of a 6.6° increase in total knee range of movement is questioned given the intra-tester measurement error of 5.5° (Brosseau et al., 1997). Similar findings of statistically significant but clinically irrelevant increases in joint range of movement after hydrotherapy have been reported by others (Templeton et al., 1996; Rintala et al., 1996). One of the problems in demonstrating clinically important increases in joint motion relates to the baseline values of knee range of movement. This was approximately 125° which is considered within the normal range and represents a ceiling effect against further increases. Within any large sample it is possible that some individuals would present with reduced knee range of movement and subgroup analyses of those with a specified level of deficit could be employed in future trials to strengthen the belief that hydrotherapy elicits clinically meaningful increases. Alternatively, the inclusion criteria could limit entry to patients with clearly defined knee impairments and the capacity for change, this would however limit the external validity of the trial.

The finding that mood and tension, measured by the affect scale (AIMS2), was significantly enhanced at follow-up in hydrotherapy patients is worth comment particularly because significant positive correlations were noted between the Ritchie index at post-test and affect at follow-up. It therefore seems plausible that improvements in tenderness which occurred by the end of treatment but which were not altogether maintained at follow-up 3 months later, may have primed improvements in mood which had already begun by the end of treatment. While a causal relationship cannot be established by correlation, these findings are in line with some results from cognitive therapy which show that psychological improvement often takes longer to develop than physiological change, and tends to follow it. This appears to demonstrate that important psychological changes may follow physiotherapy treatments and is one of the values of longitudinal studies which include the measurement of psychological variables. Given that Crotty et al. (1994), showed psychosocial variables to be as important as disease and pain in determining function, this is an extremely important finding.

This study represents the largest examination, to date, of hydrotherapy and its components in patients with rheumatoid arthritis. Whilst quantitative improvement was small, but nonetheless significant, the clinical significance needs to be addressed. Patients undergoing hydrotherapy experienced a reduction in joint tenderness of 5.8 on the Ritchie scale (range 0 – 78) which represents a 27 % change. In terms of the Ritchie Index scale this means that almost 3 joints which had scored 2 (tenderness and wince) at baseline would, after hydrotherapy, scored 0. Alternatively, approximately 6 joints scoring 1 at baseline would score 0 at post-test. Clinically, this may be judged as significant according to recent American College of Rheumatology standards of response (van Riel and van Gestel, 2000). Furthermore, the effect size for the improvement seen in joint tenderness in the hydrotherapy group was 0.58 which represents a clinically important change according to Lineker's definition that an effect size greater than 0.3 is clinically relevant (2000). The use of this definition suggests that the improvement seen in mood and tension in the hydrotherapy group was also clinically important. Whilst of clinical relevance the effect was small as judged by the work of Kazis and colleagues who studied the links between effect size and health status change (1989). The beneficial changes in the hydrotherapy group are supported by others who suggest that demonstrable objective improvement from hydrotherapy is small (Lineker et al., 2000; Stenstrom et al., 1991; Minor et al., 1989). Stenstrom et al. (1991), suggested that limitations of present outcome measures are a factor given the patients' enthusiasm to participate. Lineker et al. (2000), think that program duration is a significant factor in the small changes observed following hydrotherapy and recommend controlled studies with the intervention period lasting longer than 6 months. In the present study, reflections from hydrotherapy patients suggested that the water and the exercise together increased their confidence to move freely and anecdotal comments on improved health status attributed this to the treatment. It is likely that the outcome measures used were inappropriate to capture these variables and future research should include measures of self-efficacy. Extending the duration of intervention in line with known training principles and matching the program content to the outcome variables (ie, a program to improve cardiovascular fitness would use measures of aerobic capacity as primary end-points) may increase the effect size.

The finding that land relaxation patients had negative effects in terms of pain and beliefs in pain control supports the finding that the exercise component of hydrotherapy is of central importance. Additionally, the finding that exercising patients and immersion patients experienced reduced pain at post-test supports the theory that both components of hydrotherapy are required for effective benefit. Patients frequently report that hydrotherapy enables better performance than land exercise and given the reduction in joint tenderness it is plausible to speculate that this enhanced their ability to exercise. This may have promoted a sense of achievement and development of greater self-efficacy (Ahern et al., 1995) as suggested by the improved emotional and psychological state at follow-up. An enhanced ability to exercise in water may also produce a greater aerobic demand than on land because of the resistance of the water. A greater aerobic demand may stimulate a cardiorespiratory training effect leading to improved exercise tolerance which would facilitate improved neuromuscular function because patients could exercise for longer and/or at a greater intensity. An improved aerobic capacity is desirous, not least because of its cardioprotective effects but also because it may reduce the debilitating fatigue experienced by RA patients. Furthermore, some studies suggest a positive association between enhanced fitness and psychological well-being (McAuley and Rudolph, 1995; Weyerer and Kupfer, 1994; Morgan, 1994), although this has recently been disputed (Lawlor and Hopker, 2001). In the present study measures of cardiorespiratory fitness were not included and the measures selected did not show direct improvement in neuromuscular function, either because of lack of sensitivity or as Stenstrom et al. (1994b), discuss the inability to integrate new skills into activities of daily living. However, the inclusion of physical function tests may have captured neuromuscular change and should be incorporated into future studies. As a mechanism for therapeutic change an aerobic stimulus is appealing especially as this is claimed for hydrotherapy. At present the evidence for this claim in patients with RA is equivocal and studies to date have not considered the effects of the physical properties of the water in determining the energy costs of exercise. Buoyancy supports the body weight, reducing postural muscle activity and maximal oxygen uptake (VO_{2max}) compared with land (Sugajimo et al., 1996). Conversely, resistance to movement in water results from the greater viscosity and drag forces than in air. Resistance increases with velocity, therefore it is possible that energy expenditure could be greater in water. A first step towards substantiating the claims of aerobic capacity increase in hydrotherapy would be to compare the cardiorespiratory responses of a specified task on land and in water. If an aerobic stimulus does occur with RA patients undergoing hydrotherapy then it may, in subsequent studies, be possible to relate aerobic capacity change to functional benefit. In this way treatment regimes may be optimised by concentrating on aerobic conditioning, which by virtue of the warmth and buoyancy of the water may be result in greater patient adherence than land based exercise. The next chapter will develop a methodology to examine cardiorespiratory responses in water.

In conclusion, a controlled trial, investigating the effects of hydrotherapy, a combination of water and exercise, with its components showed that hydrotherapy gave superior benefit, in terms of physical and psychological functioning, to that experienced as a result of trial participation. Whilst these results are moderate in effect they provide justification for continuing investment into hydrotherapy.

CHAPTER 5

THE DEVELOPMENT OF AN EXERCISE TEST IN WATER

5.1. INTRODUCTION

The previous study demonstrated that hydrotherapy provided superior therapeutic benefit than either exercise or immersion on its own in patients with RA. The exercise component was considered to be of central importance leading to speculation that an increase in aerobic capacity may have been a mediating factor given the physical properties of the water. Patients may have had to work harder in water than on land to overcome the resistance of the water and even a moderately low exercise intensity could improve cardiorespiratory function in deconditioned RA subjects, resulting in improved health status. However, the opposing effects of viscosity and buoyancy on ease of movement could challenge this hypothesis. Investigation of these effects on energy expenditure may clarify the mechanism whereby RA patients in the hydrotherapy group experienced therapeutic benefit.

The determinants of energy expenditure differ in water compared to land because of the viscosity and buoyancy (Hall et al., 2001). The viscosity of water increases the resistance to movement and drag forces increase partly as a log function of velocity (Becker, 1997). Therefore as speed increases so does resistance. For this reason it is possible that exercise in water demands greater energy expenditure than similar exercise on land. Conversely, the effects of buoyancy can serve to minimise energy expenditure because less energy is required to lift the body weight against gravity. Therefore, given the opposing effects of buoyancy and resistance the energy expenditure in water may be less, similar to, or more than on land. The speed of movement and water depth are critical to the energy demands of exercise in water. At slow speeds in chest-deep water, when resistance is minimal, buoyancy dominates and as speed increases so does the resistance which requires greater muscle force to overcome it compared to similar speeds on land (Nakazawa et al., 1994). Given that patients with RA have reduced muscle strength compared to age and sex-matched normals they may be unable to generate the speeds in water which are required to stimulate an aerobic training response despite the fact that they reach maximal HR at a lower absolute workload than controls (Minor et al., 1988). This may be examined during a progressive exercise test in water with $\dot{V}O_2$ as the dependent variable which is the accepted single best measure of aerobic capacity or cardiorespiratory fitness.

In addition to viscosity and buoyancy, the increased hydrostatic pressure and water temperature determine the cardiorespiratory response of exercise in water. The hypervolaemia, secondary to the increased hydrostatic pressure is maintained during upright exercise in water (Christie et al., 1990; Bryne et al., 1996). Therefore, the enhanced $\dot{Q}$ and stroke volume, seen during resting head-out water immersion is maintained. Heart rate during exercise in water is affected by water depth, resulting in dampening of sympathetic nervous activity (causing bradycardia) and by water temperature in terms of thermoregulatory demands. Whilst there is an interaction between water temperature, exercise intensity and body fatness, in general HR is lower in water below 25°C for a given $\dot{V}O_2$, similar at 30°C and higher at 36°C (Cureton, 1997). In cold water the lower HR is due to peripheral vasoconstriction and in hot water reflects increases in thermal load.

The net effect of the physical properties of water during exercise is to alter the cardiovascular dynamics such that maximal oxygen consumption ($\dot{V}O_{2\,max}$) and heart rate are lower in water than on land. During walking and running activities this is attributed to the slower limb speeds generated in water, although attenuation of the sympathoadrenal responses, such as seen during cycle ergometry, await investigation and therefore cannot be ruled out. Additionally, the enhanced immersion induced preload, resulting in greater SV and lower HR, has been proposed to explain lower HR_{max}. Differences in muscle mass activation between water and land activity and the familiarity of technique may also account for the reduced maximal responses. During submaximal upright exercise in water $\dot{Q}$ and stroke volume are higher for a given oxygen uptake ($\dot{V}O_2$) and heart rate lower, similar or higher compared to land exercise (Christie et al, 1990; Sheldahl et al., 1984).

The relationship of HR to $\dot{V}O_2$ during submaximal exercise in water is related to a number of factors including the type of exercise which relates to muscle mass activation, the speed of movement which relates to exercise intensity and the interaction between buoyancy and resistance, water depth and temperature which affect the extent of the hypervolaemia and thermoregulatory demands and subject characteristics including physical fitness, skill and body fatness (Hall et al., 2001). Therefore, the HR-$\dot{V}O_2$ relationship during exercise in water may be different and the use of land based HR values to prescribe exercise intensity may over- or underestimate the energy demands of the water exercise.

5.1.1. Types of Activity in Water

Much of the research on energy expenditure during non-swimming water activity has focused on young healthy subjects and a variety of exercise types have been examined. Cycle ergometry has proved a useful research tool to examine physiological responses to exercise in water but it has not been utilized as a training method and its biomechanics appear similar, whether in water or on land (Hall et al., 2001). It remains a non-weight bearing activity in both environments and as such is not affected by buoyancy in the same way as walking and running. Furthermore, the drag forces are likely to be smaller given that the range of movement required for pedaling is smaller than in ambulatory activities. This may be the reason why maximal oxygen consumption in water equals that on land.

Walking and running in water may be divided into shallow water and deep water, depending on the depth of immersion. Shallow water activity may be defined as walking or running in water, usually waist or chest deep, during which the feet make contact with the pool bottom. Deep water running is a non-weight-bearing activity, performed in the deep end of a pool, in which the arms and legs simulate the running motion (Figure 5.1). The body is upright and the head is held out of the water usually with the aid of a buoyancy device. It has been advocated as a training aid for athletes because the impact free environment is considered to reduce the incidence of injury and allow training to continue during injury rehabilitation (Prins and Cutner, 1999; Dowzer and Reilly, 1998b). Most of the research on the effects of exercise in water has been generated from deep water running. Melton-Rogers et al., (1996), clearly demonstrated that peak cardiorespiratory responses during deep water running in 8 young, recently diagnosed RA females provided sufficient stimulus for improvement of aerobic capacity as recommended by the ACSM. However, not all patients with RA would be

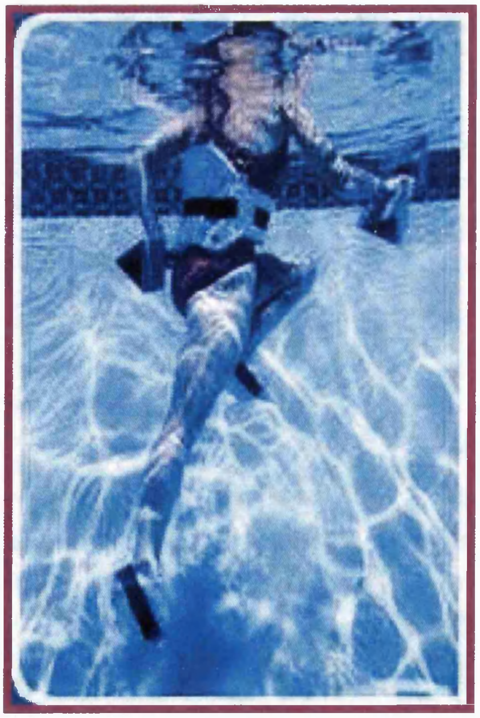


Figure 5.1 – Deep water running.

capable of performing deep water running given that subjects are suspended in deep water and make no foot contact with the pool bottom. Furthermore, Moening et al. (1993) showed, in a single subject design, that the biomechanical demands of deep water running are dissimilar from land running. Therefore, translation of any functional effects to dry land may be limited.

It is assumed that because a normal heel-toe gait pattern is performed, shallow water walking/running most closely mimics land locomotion which is considered desirable for transference of skills from water to land. Two types of shallow water ambulation, which differ in terms of the frontal resistance, are reported in the literature. Firstly, walking/running across a pool or within a swimming flume (termed shallow water walking/running in this thesis) and secondly walking on a water treadmill. The greater frontal resistance encountered during shallow water walking encourages a forward leaning posture and exaggerated gait pattern (i.e., high knee lift). Therefore comparability of biomechanical stresses between water and land cannot be assumed. To overcome these limitations water treadmills were developed. They have the advantages of easy depth control and because of the relatively small volume of water the temperature may be adjusted quickly and cheaply. Walking/running may be performed in water from ankle to chest depth using a normal gait pattern. Of all the methods of water locomotion it is considered to mimic terrestrial gait most closely and allows subjects to walk upright rather than incline forwards as seen during shallow water walking/running. Finally, the treadmill speed may be used as a measure of exercise intensity. Because of ease of adjustment of water temperature and depth and the relatively stationary position of a subject it makes a valuable research tool in the investigation of exercise responses to water activity. Furthermore, the assumption of biomechanical similarity to land walking makes it an ideal environment for examining the cardiorespiratory responses to exercise in RA patients.

Research on water treadmills is scarce compared to that on deep water running but its advantages for patients with RA make it essential to evaluate its utility as a means of increasing aerobic capacity. Walking is a functional activity whereby exercise intensity increases as speed increases. As speed increases on land ground reaction force also increases and the compressive loading through rheumatoid joints may enhance pain. However, the buoyancy of water reduces the compressive stresses on weight-bearing joints. Nakazawa et al. (1994), reported that walking in waist-deep water reduced the ground reaction force by up to 50% and therefore a water treadmill, which allows comparable gait action, may provide the best means of increasing cardiorespiratory and locomotor function.

5.1.2. Water Treadmill Exercise

During walking and running in water $\dot{V}O_2$, HR and RPE increase with speed (Bryne et al., 1996, Gleim and Nicholas, 1989). At slow walking speeds in waist-deep water ($\leq$ 3.5 km·h^{-1}) $\dot{V}O_2$ is greater but HR and RPE are similar to land (Bryne et al., 1996; Napoletan and Hicks, 1995; Gleim and Nicholas, 1989). The relatively lower HR in water was attributed to the enhanced preload secondary to the hypervolaemia of immersion. As speed increases above 3.5 km·h^{-1} HR and RPE, like $\dot{V}O_2$, in water become significantly greater than on land.

Bryne et al. (1996), noted that increasing speed on land from 3.5 to 5.5 km.hr^{-1} increased energy requirements by approximately 25% whereas in water the increase was 50%, suggesting that moderate increases in walking speed have large effects on energy expenditure. However this effect has been shown to be non-linear in young healthy subjects with the steepest increases in $\dot{V}O_2$ occurring between 2.4 and 5.6 $km.hr^{-1}$ (Gleim and Nicholas., 1989). This has implications for clinical practice, especially for deconditioned patients, and the clinician should appreciate that the metabolic and cardiovascular increments are greater where the slope of the curve is steeper. Whether similar speed range effects occur in older patients or those with low physical fitness remains to be ascertained.

Water depth affects energy expenditure and RPE with depths below the waist requiring greater metabolic demands than higher depths (Napoletan and Hicks, 1995; Gleim and Nicholas, 1989). At walking speeds of greater than 4.8 $km{\cdot}h^{-1}$ the energy requirements of walking in chest deep water were less than levels below the thigh (Gleim and Nicholas, 1989). These results reflect the interaction between buoyancy and water resistance; at water depths above the waist the effects of buoyancy dominate, especially when running, and at depths below the thigh water resistance impedes movement.

The differences of gait pattern on the metabolic demands of water treadmill exercise can be clearly seen from two studies. Bryne et al. (1996) observed significantly greater $\dot{V}O_2$ when walking in chest deep water at $5.5km.hr^{-1}$ whereas Napoletan and Hicks (1995), showed similar energy requirements to land when running at this speed. The differences suggest that running affords a prolonged flight phase during which the subject floats momentarily while the treadmill belt passes underneath. In allowing their subjects to run on the water treadmill Napoletan and Hicks (1995), did not know the actual running speed making a comparison of speeds invalid. Furthermore running at this speed on land is uncomfortable and inefficient. The effects of a prolonged flight phase on counteracting the additional work necessary to move the legs against the resistance of the water is confirmed by Gleim and Nicholas (1989). They showed that $\dot{V}O_2$ was higher in waist deep water than on land up to 8 km.hr^{-1}, thereafter it was similar. Whilst the transition between walking and running was unknown the authors suggested that this occurred at 8 km.hr^{-1}.

Because of the linear relationship between HR and $\dot{V}O_2$ on land HR is a useful and convenient method of prescribing and monitoring of exercise intensity. Therefore it is important to be certain, given the cardiovascular effects of head-out water immersion, that this relationship is maintained during water exercise and is similar to that on land so that land-derived values may be utilized. However, Gleim and Nicholas (1989), showed that HR was higher for a given $\dot{V}O_2$ in waist deep water than on land at water temperatures of 30°C, which is considered thermoneutral, and 36°C. The effect was more apparent in the hotter water suggesting that the effects of the hypervolaemia were overcome by the thermal stimulus to increase HR. Also, the effects were more prominent at higher exercise intensities (>20ml·kg^{-1}·min^{-1}) which may explain why Bryne et al. (1996) reported the converse in a similar sample of subjects (at approximately 10 ml·kg^{-1}·min^{-1} HR was lower). These results have important implications for exercise prescription and suggest that land based HR would underestimate metabolic demand during waist deep exercise in water. Exercising at water depths below the waist have no effect on the HR-$\dot{V}O_2$ relationship and therefore land based calculations should be accurate. However, information on the relationship at different depths in water above 30°C is unavailable.

Depending on the speed of movement, mode of locomotion and water depth and temperature the $\dot{V}O_2$ response to water treadmill ambulation may be lower, similar or higher than land treadmill activity. Familiarity with water treadmill walking/running may also affect the physiological effects but this has not been considered in the studies reported. Yamaji et al., (1990) and others (DeMaere and Ruby, 1997; Frangolias et al., 1996), showed that HR responses to deep water running were higher in novices than those familiar with the technique. Information on subject familiarization was not included in the water treadmill studies and given the relatively greater increases in HR whilst performing a novel task this omission should be rectified in future studies. Furthermore, standardization of the gait (eg, constancy of heel-toe gait as speed increases, handrail use, hand position to prevent sculling-type movements) is not reported. Given that a higher HR for a specified $\dot{V}O_2$ occurs during upper limb versus lower limb exercise the HR – $\dot{V}O_2$ relationship may have been affected by arm use. For this reason future studies should standardize the gait pattern.

Data on the cardiorespiratory responses to water treadmill walking is limited to young healthy subjects and extrapolation to older patients and those with locomotor difficulties may be inappropriate given the attenuation of cardiovascular response in healthy elderly subjects during resting head-out water immersion (Miwa et al., 2000 and 1996; Takeshima et al., 1997). At present there are no data on the cardiorespiratory responses to water treadmill walking in patients with RA. In particular, information concerning the HR-$\dot{V}O_2$ relationship is unavailable and the feasibility of producing an aerobic stimulus given the opposing effects of buoyancy and resistance on energy expenditure in such deconditioned patients is uncertain. Therefore a water exercise test will be developed to examine these questions.

As the water treadmill has undergone relatively little evaluation and there are concerns with regard to the testing protocols it was decided to examine the cardiorespiratory responses of healthy subjects prior to RA patients. Furthermore, there are concerns about thermoregulation during aerobic exercise in hydrotherapy pools because of the high water temperature. Therefore, a water exercise test, using the extremes of temperature encountered in hospital (36°C) and recreational (28°C) pools was included to examine the HR-$\dot{V}O_2$ relationship.

5.2. Cardiorespiratory responses to water treadmill walking in healthy females

The aims of this study were to examine the relationships between $\dot{V}O_2$, HR and RPE during land and chest-deep water treadmill walking at two water temperatures of 28°C and 36°C. It was hypothesized that, for a given speed, $\dot{V}O_2$ and RPE would be higher in water than on land. It was also hypothesized that, for a given $\dot{V}O_2$, HR would be higher in water at 36°C and lower in water at 28°C compared to land. However, before the protocol could be ascertained a number of pilot studies were completed which asked the following questions 1) how long does it take to reach steady state, 2) how much practice is required before subjects are familiar with the technique of water treadmill ambulation and 3) what speeds should be selected for examination of the cardiorespiratory responses to water treadmill ambulation. ?

5.2.1. Pilot Study 1 – Achievement of steady state

The term steady state refers to the balance between the demands placed on the body and the body's response to those demands. During aerobic exercise steady state is achieved when a balance between the rate of ATP production and the energy required by the working muscles is reached. Astrand and Rodahl (1986) recommend a minimum test stage of 5 minutes if the purpose is to achieve steady state. With the dynamic circulatory effects of immersion it was queried whether this time may be different. Therefore a pilot study was conducted to examine the time required to reach steady state in water, as assessed by $\dot{V}O_2$. Steady state was defined as a ±5% agreement between timed $\dot{V}O_2$ collections (Astrand and Rodahl, 1986).

5.2.1a. Methods

Seven healthy female subjects, aged between 21-39 years (mean and SD 31.1 ± 6.5) completed the study. Patients were recruited and completed screening and examination procedures as for the main study.

Subjects jogged on the water treadmill (Figure 5.2) in chest-deep water at 34.5°C at 7 $km \cdot h^{-1}$ for 8 minutes.

Figure 5.2 – The water treadmill consists of a reservoir and exercise chamber.

Treadmill speed and duration of exercise is altered by the operator.

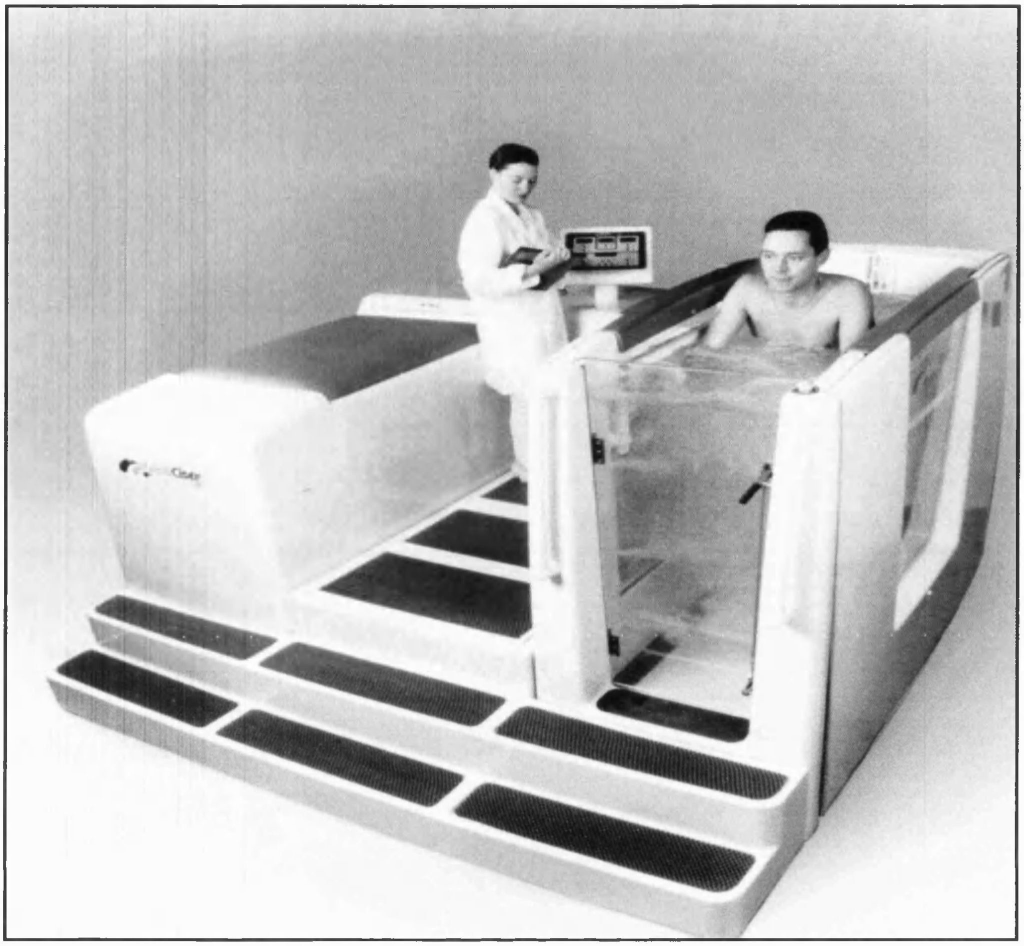
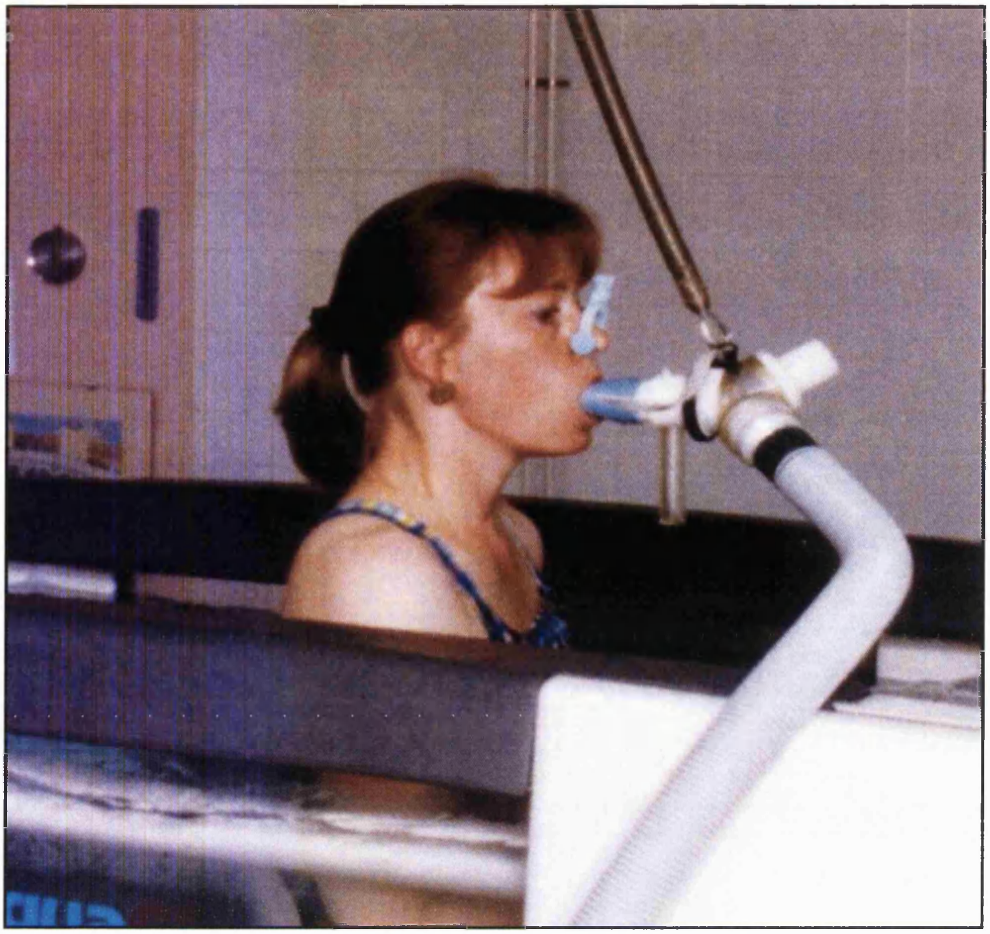


Figure 5.3 shows that expired gas was collected via open-circuit spirometry using a Hans-Rudolph valve and Douglas bags every second minute for 1 minute (ie, minutes 2, 4, 6 and 8). Gas samples were analysed using a paramagnetic O_2 analyser (OA 250 Servomex). Subjects also wore a heart rate monitor (Polar FavorTM HR) and told that the test would be terminated at their request or when 85% of their age predicted maximal heart rate was attained.

Figure 5.3 - Mouthpiece and valve in situ.



5.2.1b. Results

Table 5.1 details the means (±SD) for each of the timed collections. The variability of $\dot{V}O_2$ between collection times at minute 4 and minute 8 was below 5%, suggesting that steady state had been achieved within this time range. Therefore it was decided to limit the duration of each stage to 5 minutes.

Table 5.1 – mean (±SD) $\dot{V}O_2$ for timed collections

Collection Time (minutes)	Mean ($l.min^{-1}$) (SD)	% change between between preceding bag
2	1.14 (0.34)	-
4	1.27 (0.47)	11
6	1.25 (0.38)	1.57
8	1.24 (0.35)	0.8

5.2.2. Pilot Study 2 – Familiarisation time

Studies on water treadmill activity have not reported on subject familiarity or prior participation in such a task. Given that studies on deep water running show that familiarity is a factor in determining the cardiorespiratory responses it was considered necessary to examine the practice time required for subjects to feel comfortable in their technique (Yamaji et al., 1990; DeMaere and Ruby, 1997; Frangolias et al., 1996).

Nine female subjects aged from 21-57 years (35.6 ± 11.5) completed the study. Patients were recruited and completed screening and examination procedures as for the main study. At the first practice session subjects were taught the correct technique of water treadmill walking and running. Treadmill walking in water at 34.5°C was performed with a heel-toe gait with the arms swinging reciprocally. For ease of motion within the confines of the treadmill the elbows were flexed to 90° with the forearms in mid-prone. The fingers were loosely flexed into a loose fist to prevent subjects from sculling through the water at higher speeds. As speed increased subjects were encouraged to maintain the correct walking pattern until the resistance of the water made it impossible. When running subjects were encouraged to move through the water rather than bob up and down. The arm position remained the same as walking.

Patients' comments on the comfort of their technique and observation of the development of a reliable technique suggested that 3 practice sessions of 10 minutes was sufficient. This formed the familiarization training used in the main study.

5.2.3. Pilot Study 3 – Treadmill speed selection

To ascertain what treadmill speeds should be selected the subjects who had completed the familiarisation study walked and ran in the water and land treadmills at speeds between 1.5 and 9.5 $km \cdot h^{-1}$, in 1.5 $km \cdot h^{-1}$ increments in chest deep water at 34.5°C. Subjects self selected their mode of ambulation and for each speed were asked to rate the activity as easy or hard. At 5.5 $km \cdot h^{-1}$ subjects reported that the activity was hard in the water treadmill only. Subjects reported that they could barely keep up with the belt speed and this was evidenced when subjects had to grab the handrails to pull themselves back to the centre of the treadmill. In water, at approximately 6.5 $km \cdot h^{-1}$ subjects were no longer able to walk because of the resistance of the water. At this speed on land subjects were experiencing a fast walk. Observation of the gait pattern during running in water showed that subjects appeared to float through the water as reported by Gleim and Nicholas (1989). Subjects reported that running allowed them to use the effects of buoyancy and ignore the speed of the belt. Because running negates the actual treadmill speed it was decided to limit examination of the cardiorespiratory responses to walking. Furthermore, this is a functional activity for RA patients. Based on subjects responses 3 speeds (3.5, 4.5 and 5.5 $km \cdot h^{-1}$) were selected on the basis of slow, moderate and fast walking.

5.2.4. METHODS

5.2.4a. Subjects

Eight healthy volunteer females with a mean age of 30.25 (SD ±6.3) years were recruited from among staff following an advertisement for volunteers in the hospital newsletter. The number of subjects was based on the sample sizes used in previous research of this kind. The sample was limited to female subjects because much of the research on water treadmill activity has considered men. In terms of RA prevalence men make up less than 50% of the RA population. Therefore, it was considered more prudent, especially with a small sample size to exclude men from the water treadmill studies.

Subjects completed a health screening questionnaire and interview, adapted for the study from the Hydrotherapy Association of Chartered Physiotherapists Standards for Good Practice (Appendix 5.1 and 5.2). No subject reported health concerns which required them to be excluded, nor did any report recent acute illness, and all were free from chronic diseases. Information on the subjects habitual physical activity was recorded using the Allied Dunbar National Fitness Survey scoring system whereby 0 indicates no "activity of 20 minutes duration in the previous 4 weeks" and 5 represents "12 or more occasions of vigorous activity of 20 minutes duration in the previous 4 weeks" (Allied Dunbar National Fitness Survey, 1992).

The median score was 3 (inter-quartile range = 2-5). Subjects had a mean height of 1.67m (SD±0.035), body mass of 63.2kg (SD ±1.5), body mass index of 22.7 (SD ±1.5) and 26.7% body fat (SD ±1.4). The average of 3 measurements from four skin fold sites (biceps, triceps, subscapular and suprailiac) were used to estimate percent body fat, using Siri's equation (Durnin and Womerseley, 1974). Their resting HR was 68 beats·min^{-1} (SD ±6.4), standing systolic and diastolic BP 105.5 (SD ±7.6) and 70.75 (SD ±5.5) mmHg respectively.

The study was approved by the local ethics committee and subjects completed written consent forms before participating in the study (Appendix 5.3).

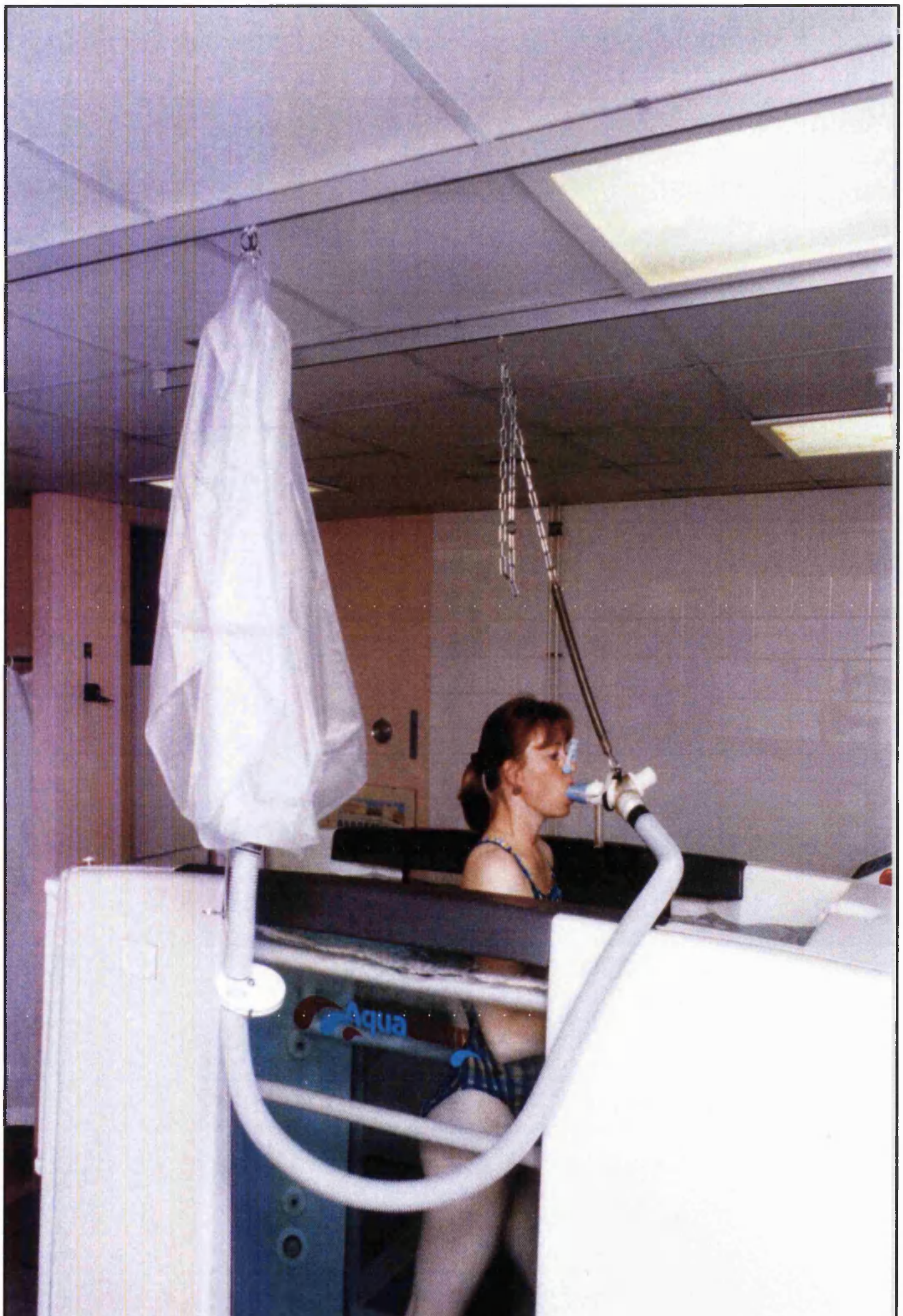
5.2.4b. Procedure

Following completion of the familiarization sessions (on both land and water treadmills) and practice with the open-circuit spirometry set-up and RPE scales subjects completed 3 treadmill tests (land, water at 28.2°C ± 0.06 and water at 35.8°C ± 0.08) which were randomly allocated, and the order of experiments was balanced between subjects. At least 24 hours separated each exercise test, which was similar. After a 2 minute warm-up period at 2.5km·h^{-1} subjects completed 3 consecutive bouts of 5 minutes duration at progressively increasing speeds (3.5, 4.5 and 5.5km·h^{-1}). During the water treadmill tests subjects were immersed to the level of the xiphoid process in water either at 28.2°C or 35.8°C. This level of immersion was selected because it offers maximum joint unloading and is therefore favoured in the hydrotherapy treatment of RA patients. Subjects were encouraged to walk using the correct gait pattern at all times. The mouthpiece was positioned one minute prior to the expired gas collection.

All exercise tests were carried out 2 hours post-prandial and subjects were asked to refrain from tea, coffee and smoking for the morning of the test. All procedures were completed in the morning between 9.00am and 12.00pm in a dedicated "Aquaciser" laboratory, specially constructed for these experiments. Figure 5.4 shows the water treadmill and subject set-up. Air temperature of the laboratory during the study was between 21° and 25°C and the humidity between 35 and 58%.

One hour prior to testing the O_2 and CO_2 pumps were switched on and the machines calibrated 15 minutes before testing began. The sample bag was "washed out" with the relevant calibration gas before filling and attaching to the analysers. The O_2 analyser was calibrated using oxygen free nitrogen, room air and a mix of 16% O_2 and 5% CO_2. The CO_2 analyser was calibrated using room air and the mix of 16% O_2 and 5% CO_2. Ten minutes prior to each exercise test Douglas bags were evacuated using a vacuum cleaner.

Figure 5.4 – Experimental set-up.



5.2.4c. Measurements

Expired gas was collected via open-circuit spirometry using a Hans-Rudolph valve and Douglas bags for the final minute of each exercise bout (Appendix 5.4). Gas samples were analysed using an infrared CO_2 analyser (PK Morgan 901, Gillingham, UK), and a paramagnetic O_2 analyser (OA 250 Servomex, Cranlea, UK). The respiratory exchange ratio (RER) was calculated from $\dot{V}CO_2 / \dot{V}O_2$. The volume was recorded using a dry gas volume meter with thermometer attached (Havard Apparatus,UK). Gas volumes were corrected to STPD and standard calculations used to calculate $\dot{V}O_2$, $\dot{V}_E$ and $\dot{V}CO_2$ (Powers and Howley, 2001). HR was measured in the final minute of each bout using HR monitors (Polar Favor™ HR monitors) as was stride frequency (S_f) by counting the number of strides. Ratings of perceived exertion (RPE) using Borg's 6-20 scale were also recorded in the final minute of each bout (Borg, 1982). The psychometric properties of the 15-grade scale have shown it to be a reliable and valid instrument to measure perceived exertion (Noble and Robertson, 1996). Subjects pointed to the relevant number on the scale (displayed on a waterproof sheet) and their choice was checked by the researcher who asked "do you mean number X?". A thumbs-up signal from the subject confirmed the correct response. Two scales were completed after the method of Svedenhag and Seger (1992): one for the legs and one for breathing representing peripheral muscle and respiratory-metabolic signals respectively. Standardised verbal and written instructions for completing the RPE scales were given to subjects during the familiarization period and prior to each walking test (Appendix 5.5). Blood pressure, using a manual sphygmomanometer and after the technique described by Perloff et al. (1993) was recorded on the following occasions: a) standing on land before exercise, b) standing immersed on the water treadmill immediately before exercise, c) immediately exercise finished, d) 5 and 10 minutes after the end of exercise whilst standing on land. Because it was not possible to make measurements of core body temperature we recorded sublingual temperature before and after the exercise session to ensure no major changes. No subjects showed changes in temperature of greater than 1°C.

Speed calibration of land and water treadmills was conducted at monthly intervals and after servicing. Calibration was performed with a subject *in situ* and in the case of the water treadmill, the subject was immersed to the chest. The treadmill belt was measured and the time taken for 20 revolutions recorded throughout the speed range. Velocity was then calculated from distance divided by time. Regression equations showed that both treadmills underestimated the true speed and therefore appropriate adjustments were made during the treadmill study (Figure 5.5). These effects were consistent over time. A level gradient for each treadmill was confirmed by the use of a spirit level (Cooper and Storer, 2001).

5.2.4d. Statistical analysis

Exploratory data analysis, including examination of descriptive statistics for outliers, skewness and kurtosis showed that the distribution of scores was normal. Differences between treadmill condition, speed and water temperature were examined using two-way ANOVAS with repeated measures. When significant F values of $P \leq 0.05$ were found *post-hoc* testing using Tukey's procedure were employed to isolate the significant differences. When variables were unaffected by water temperature the mean of the hot and cold water was used in the statistics. The Friedman test was used to examine overall differences in the RPE data. When significant this was followed by the Wilcoxen test and Bonferroni correction factor. Differences between relationships were tested using a one-way ANOVA after a simple linear regression model estimated the dependent variable, for a given level of independent for each patient, and tests for normality of the response variable were satisfactory. This was followed by Tukey's *post-hoc* test if significant F values were found. A P-value of <0.05 was chosen as the level of statistical significance. All values are expressed as mean ± SD. Data was analysed using SPSS.

5.3. RESULTS

Oxygen consumption ($\dot{V}O_2$), ventilation ($\dot{V}_E$) and carbon dioxide production ($\dot{V}CO_2$) increased with speed during water and land walking (P<0.001). $\dot{V}O_2$, $\dot{V}_E$ and $\dot{V}CO_2$ were not affected by water temperature. Figures 5.6-5.8 show that at 4.5 and 5.5km·h^{-1} $\dot{V}O_2$, $\dot{V}_E$ and $\dot{V}CO_2$ were significantly higher in water than on land (P=0.012, 0.03 and 0.013 respectively). The respiratory exchange ratio (RER) increased significantly with speed during water treadmill walking at 28.2°C (P <0.003). Between the speeds of 3.5 and 4.5 km·h^{-1} on land and in water at 35.8°C RER increased significantly (P<0.017). It was not affected by water temperature nor treadmill condition (see Table 5.2). Figure 5.9 shows the $\dot{V}_E$-$\dot{V}O_2$ relationship, the range of which is extended during water treadmill exercise. V_E did not differ significantly in water for a given $\dot{V}O_2$.

HR increased significantly on land and in water at both temperatures as speed increased (F=110.9, df=2,14; P=0.001). HR was significantly greater in water at 35.8°C compared to water at 28.2°C at all speeds (P<0.003). Furthermore, HR was significantly greater in water at 35.8°C compared to land treadmill walking at 4.5 and 5.5 km·h^{-1} (P<0.002). On land, HR increased linearly, but in water at 28.2°C showed a significant interaction effect (Figure 5.10). At 3.5km·h^{-1} HR was significantly lower in water at 28.2°C than on land, and similar at 4.5 (P=0.007). Whilst the HR appears significantly higher at 5.5 km·h^{-1} it was not statistically significant (P=0.059). The HR-$\dot{V}O_2$ relationship shows that the line is shifted to the right in water at 28.2°C such that for a $\dot{V}O_2$ of 0.9 l·min^{-1} HR was lower by 15.6 and 11.2 beats·min^{-1} respectively compared to water at 35.8°C and on land (P=0.001) (Figure 5.11). The HR-$\dot{V}O_2$ relationship is similar between water at 35.8°C and land at all exercise intensities.

As speed increased a significant increase in RPE for the legs was observed during land and water treadmill (both at 28.2°C and 35.8°C) walking (P<0.016). There were no differences in perceived exertion between water temperatures for either RPE-legs or RPE-breathing. At 3.5 km·h^{-1} RPE-legs was similar between conditions; above this speed the perception of effort was significantly greater in water than on land (P <0.001) (Figure 5.12). The relationship between RPE-legs and $\dot{V}O_2$ was similar between land and water. RPE-breathing increased significantly in water but not on land at speeds ≥ 4.5 km·h^{-1} (P<0.05). At 3.5 and 4.5 km·h^{-1} RPE-breathing was similar across procedures but significantly greater in water than on land at 5.5 km·h^{-1} (P=0.008) (Table 5.2).

Water immersion *per se* had no effect on either systolic (SBP) or diastolic blood pressure (DBP) (see Table 5.3). After exercise in water at 28.2°C and 35.8°C, but not on land, SBP increased significantly (F=9.14, df=2,14; P=0.002). Post-hoc testing showed that the greatest increases in SBP immediately after exercise occurred in water at 35.8°C (F=10.8, df=1,7; P=0.013). Diastolic blood pressure did not change after exercise in water at 28.2°C or 35.8°C or on land. Water immersion per se did not affect the pulse pressure (PP) but exercise in water resulted in a significantly greater PP than on land (P<0.001). Figure 5.13 shows that after exercising in water at 35.8°C PP was significantly greater than land (t=4.3, df=7; P=0.004). Mean arterial BP did not alter as a result of immersion, exercise or environment. BP responses returned to baseline within 5 minutes of the end of exercise as shown by the pulse pressure graph in Figure 5.13.

Figure 5.14 shows that cadence increased significantly with speed during water and land treadmill walking (F=86.9, df=2,14; P=0.001). In water cadence was approximately 27 strides·min^{-1} (SD±6.5)slower than on land (F-121.7, df=2,14; P=0.001). At 4.5 and 5.5 km·h^{-1} in water at 28.2°C and 35.8°C stride frequency was similar. However at 3.5 km·h^{-1} subjects walked 9.65 strides·min^{-1} slower in water at 35.8°C than in water at 28.2°C (t=26.8, df=1,7; P=0.001). Table 5.2 shows the $\dot{V}O_2$ cost per stride at each speed. It was significantly greater in water, both at 28.2°C and 35.8°C than on land at all speeds (P<0.005).

Figure 5.5 - Land and Water Treadmill Calibration Curves

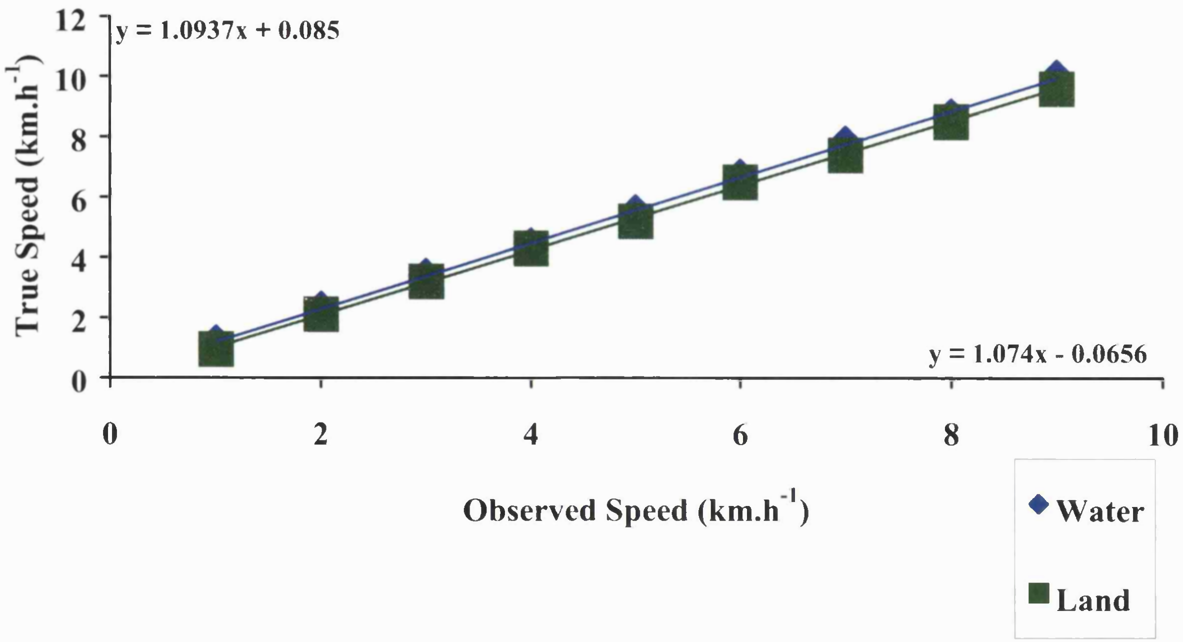
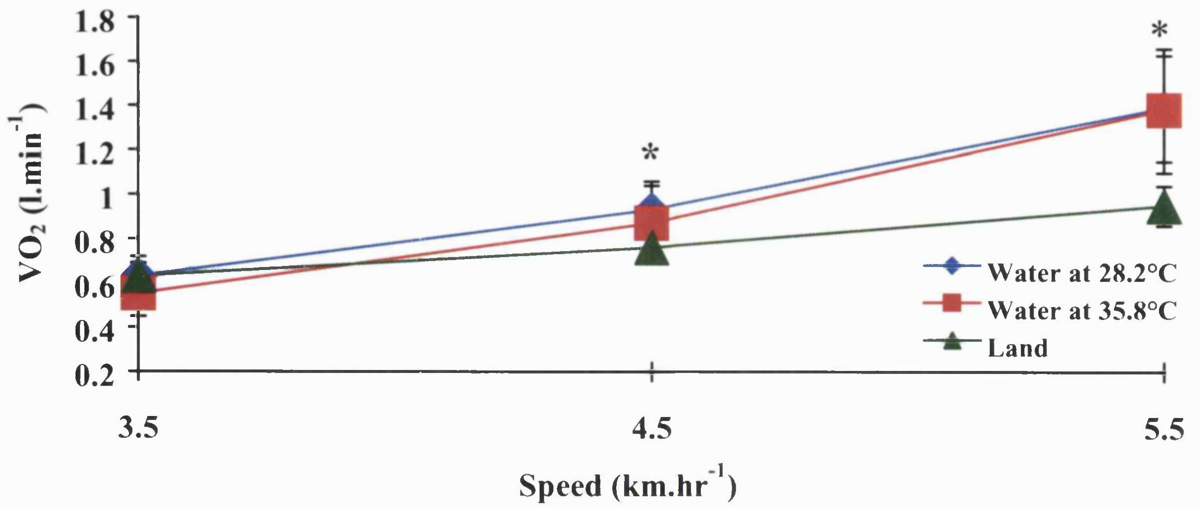
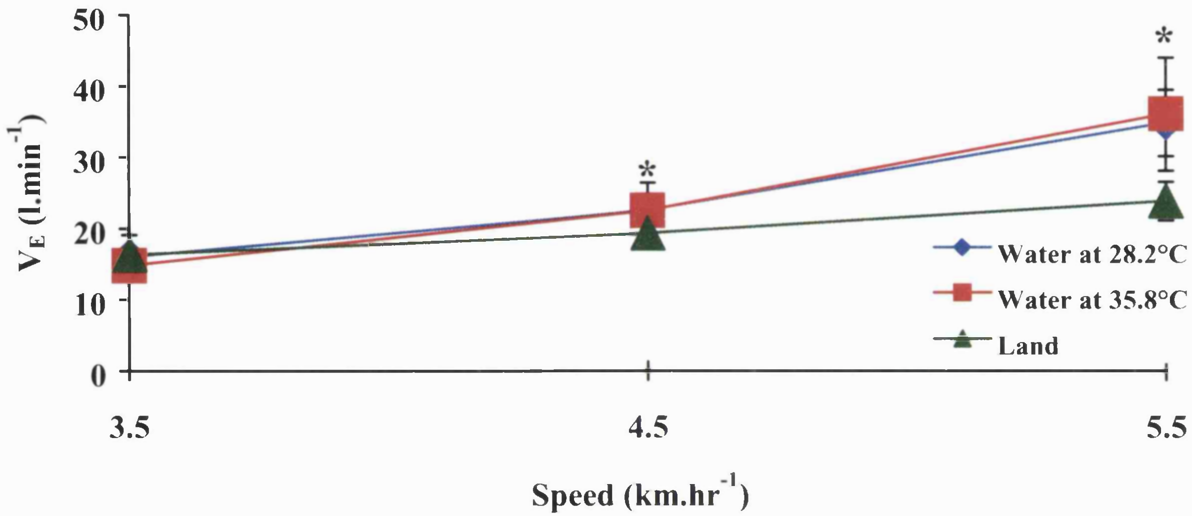


Figure 5.6 - VO_2 versus Speed



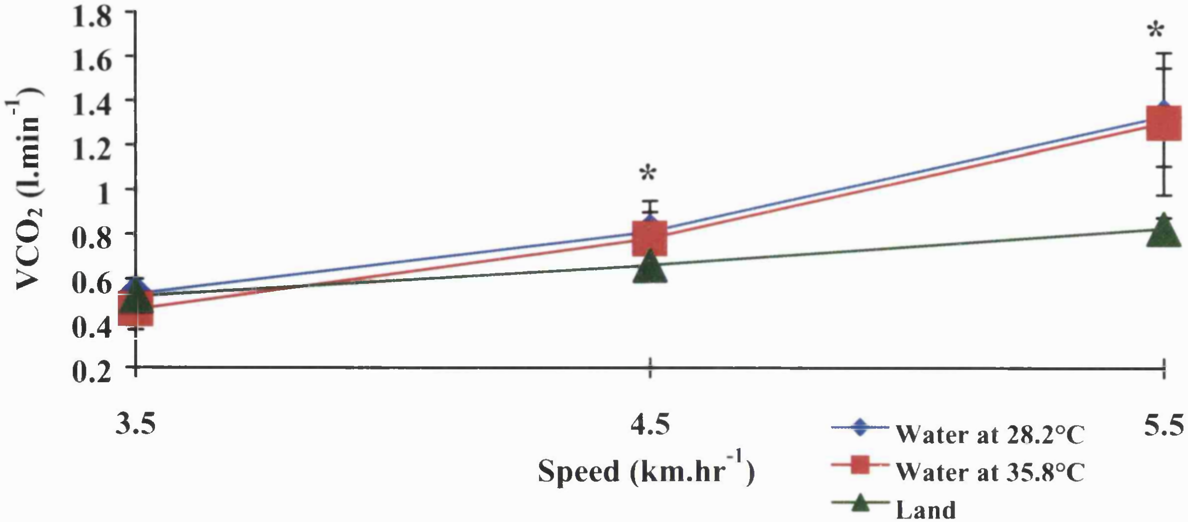
As speed increased on land and in water at both temperatures VO_2 increased ($F=142.5$, $df=2,14$, $P<0.001$). * $p=0.003$ - VO_2 was significantly higher in water at both temperatures compared to land.

Figure 5.7 - V_E versus Speed



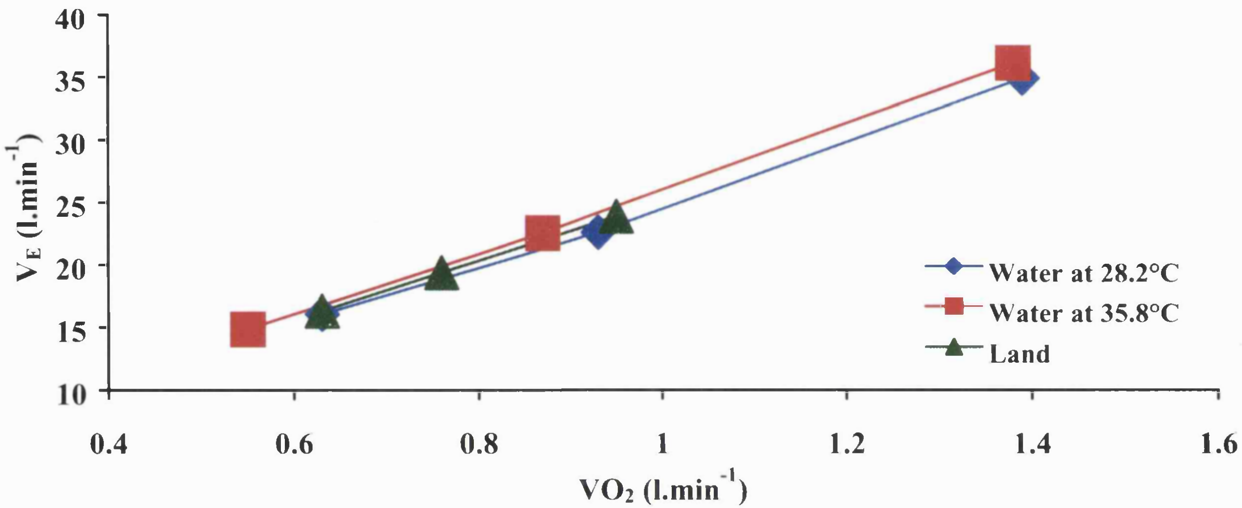
As speed increased on land and in water at both temperatures V_E increased (F=98.5, df=2,14, P<0.001). * p =0.03 - V_E was significantly higher in water at both temperatures compared to land.

Figure 5.8 - VCO_2 versus Speed

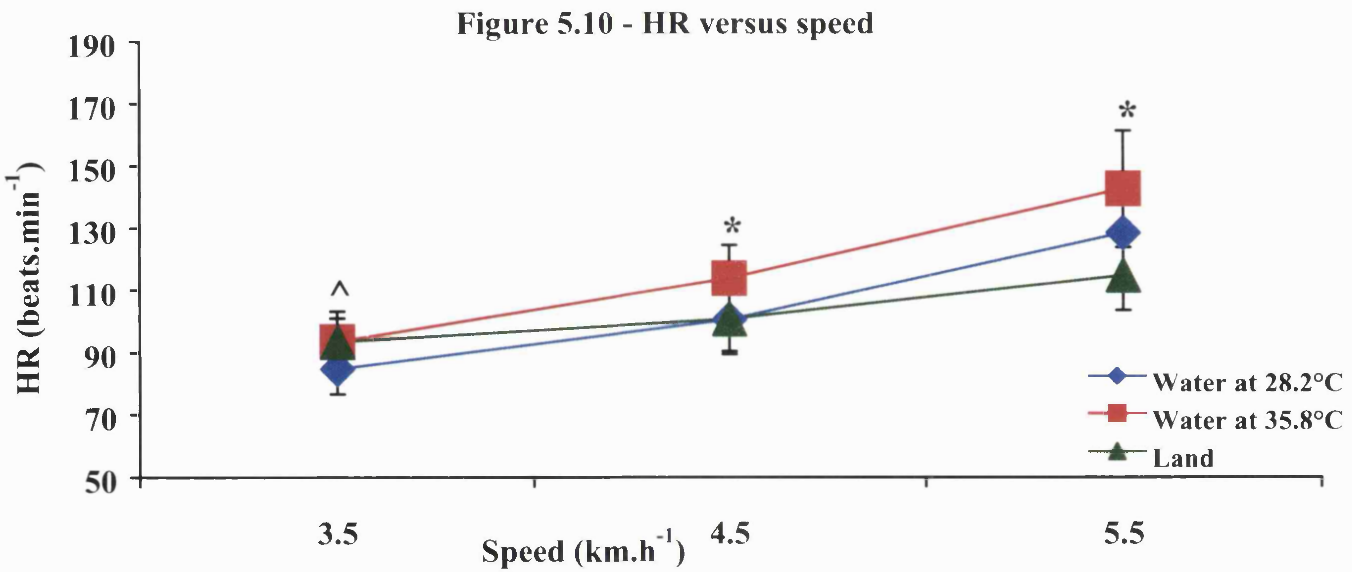


As speed increased on land and in water at both temperatures VCO_2 increased ($F=108.5$, $df=2,14$, $P<0.001$). * $p = 0.013$ - VCO_2 was significantly higher in water at both temperatures compared to land.

Figure 5.9 - V_E-VO_2 Relationship

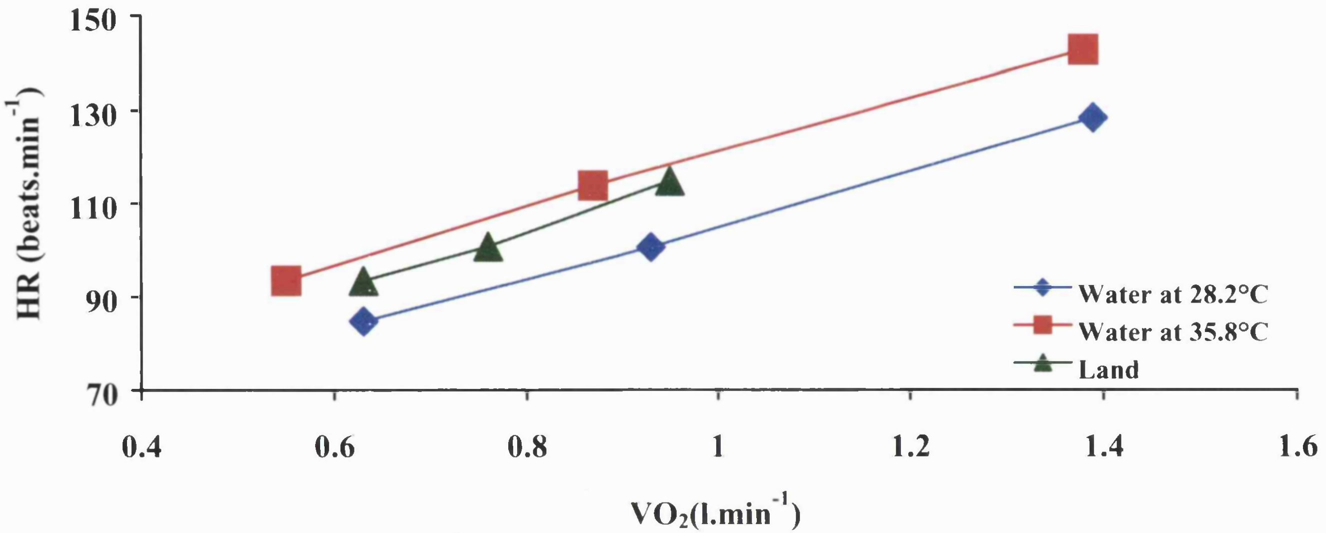


V_E did not differ significantly in water for a given VO_2.



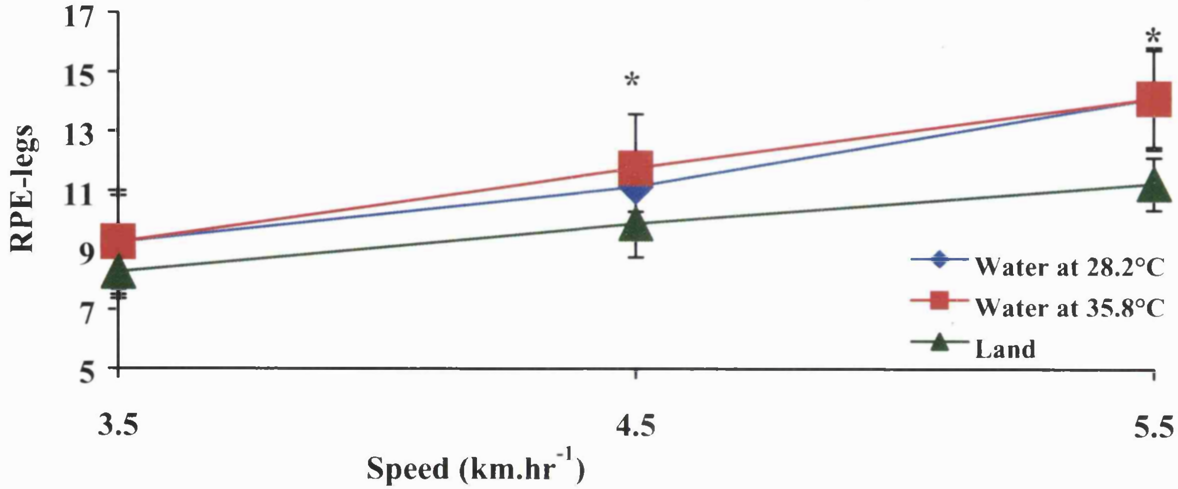
As speed increased on land and in water at both temperatures HR increased (F=110.9, df=2,14, P=0.001). * HR was significantly higher in water at 35.8°C compared to land (P<0.002). ^ HR was significantly lower in water at 28.2°C compared to land (p=0.007).

Figure 5.11 - HR-VO_2 relationship



For a given VO_2 of 0.9l.min^{-1} HR is signficantly lower in water at 28.2°C than on land (P=0.001).

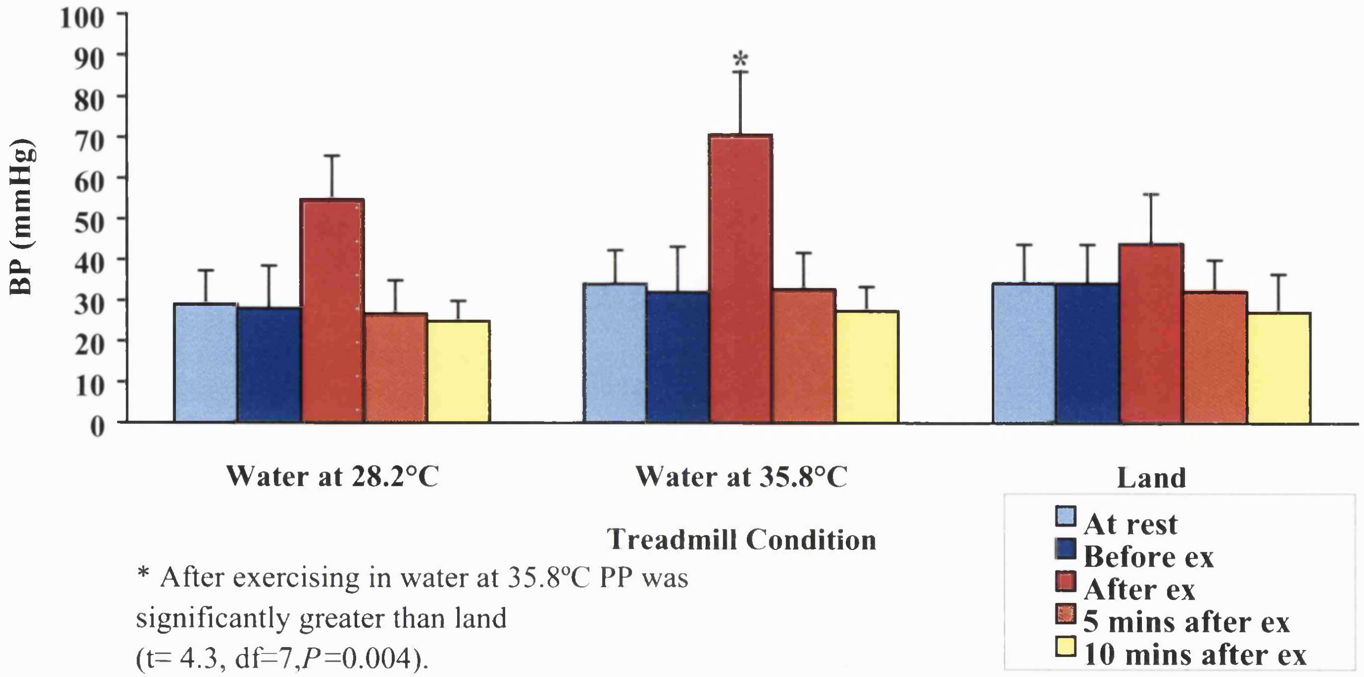
Figure 5.12 - RPE-legs versus Speed



As speed increased on land and in water at both speeds RPE-legs (P<0.001).

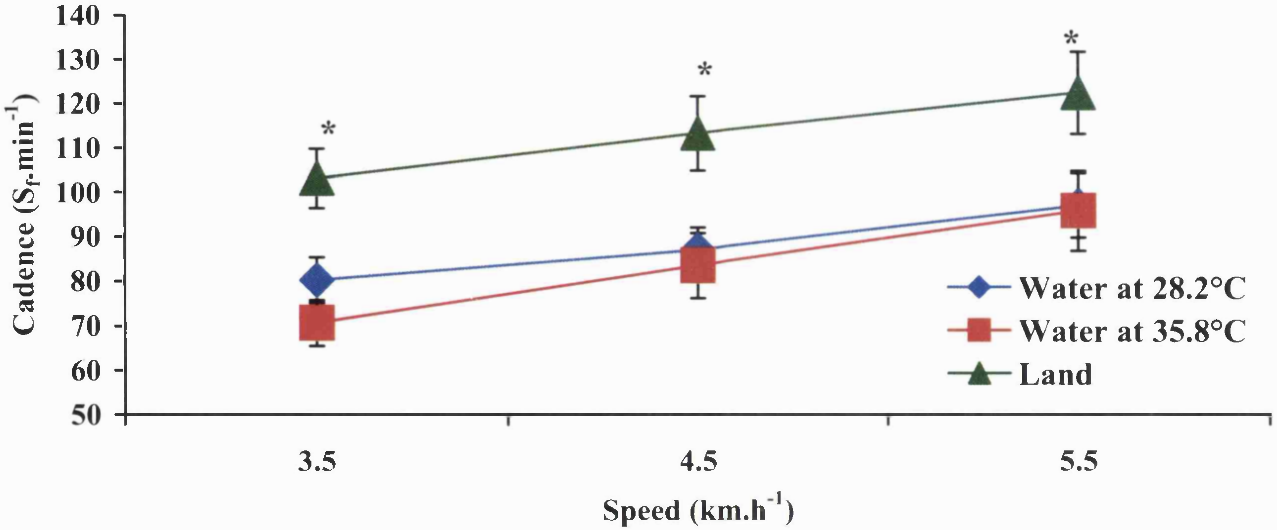
* P=0.016 - RPE-legs was significantly higher in water at both speeds compared to land.

Figure 5.13 -Pulse pressure for each condition



* After exercising in water at 35.8°C PP was significantly greater than land ($t= 4.3$, $df=7$, $P=0.004$).

Figure 5.14 Cadence versus speed



* Cadence was significantly reduced in water compared to land (F=121.7, df=2,14,*P* =0.001).

Table 5.2 - mean (±SD) for respiratory exchange ratio (RER) ratings of perceived exertion for breathing (RPE-Br) and VO_2 cost per stride ($\dot{V}O_2$ /str; ml·min^{-1}).

	Water at 28.2°C			Water at 35.8°C			Land		
Speed (km·h^{-1})	**3.5**	**4.5**	**5.5**	**3.5**	**4.5**	**5.5**	**3.5**	**4.5**	**5.5**
RER	0.84 (0.06)	0.88 (0.05)	0.96 (0.04)	0.84 (0.05)	0.9 (0.05)	0.94 (0.06)	0.83 (0.05)	0.87 (0.06)	0.87 (0.05)
RPE-Br	9.13 (1.4)	10.5 (0.8)	12.25$ (1.6)	9.5 (1.8)	10.88 (1.6)	12.5$ (1.3)	9 (1.6)	9.88 (1.4)	11 (1.3)
VO_2/str	7.8^ (0.9)	10.4^ (1.2)	14.43^ (2.6)	7.83^ (1.41)	10.48^ (2.08)	14.39^ (2.8)	6.4 (0.6)	6.73 (0.4)	7.8 (.76)

RER increased significantly with speed ($P \leq 0.001$).

$ RPE for breathing was significantly greater during water walking than land at 5.5kmhr^{-1} ($P = 0.008$).

^ The VO_2 cost per stride was significantly greater in water than on land at all speeds ($P < 0.05$).

TABLE 5.3 - Mean (±SD) systolic and diastolic blood pressures on land before exercise, in water before exercise and after exercise in water and on land (mmHg)

	Systolic Blood Pressure			Diastolic Blood Pressure		
	At rest: land	Before exercise	After exercise	At rest: land	Before exercise	After exercise
Water at 28.2°C	104.75 (10.8)	101.25 (8.1)	118.75* (10.3)	75.75 (7.4)	73.25 (12.2)	64 (3.5)
Water at 35.8°C	103.5 (10.2)	98 (8.1)	124.75* & (10.6)	69.5 (6.2)	66 (6.7)	54 (8.2)
Land	108 (8.4)	108 (8.4)	117 (9.0)	73.75 (8.8)	73.75 (8.8)	73 (4.7)

* After exercise in water at 28.2°C and 35.8°C SBP increased significantly (F=9.14, df=2,14, P =0.002).

& SBP increased significantly more after exercise in water at 35.8°C than in water at 28.2°C or on land (F=10.8, df=1,7, P =0.013).

5.4. DISCUSSION

5.4.1. Effects of Speed

In this study $\dot{V}O_2$, $\dot{V}_E$, $\dot{V}CO_2$, HR, RPE-legs increased significantly as speed increased and confirms previous reports (Bryne et al., 1996, Gleim and Nicholas, 1989). At 3.5 km·h^{-1} $\dot{V}O_2$, $\dot{V}_E$, $\dot{V}CO_2$ in water were similar to land suggesting that walking at this speed minimized the drag forces of water. Furthermore, the low RPE-legs scores and their similarity between treadmill conditions confirms that the effects of water resistance were minimal allowing the effects of buoyancy to dominate. Whilst similar RPE scores have been noted by others, $\dot{V}O_2$ was reported to be significantly higher when walking on the water treadmill at 3.5 km·h^{-1} (Bryne et al., 1996; Napoletan and Hicks, 1995; Gleim and Nicholas, 1989). The differences between studies may reflect the level of immersion and subsequent effects of buoyancy. Gleim and Nicholas (1989) clearly stated the level of immersion in their study was waist-deep but Bryne et al. (1996) reported that immersion varied from mid-abdominal to mid-sternal depending on the subject's height. The effects of buoyancy on percentage weight bearing have shown that immersion to the xiphoid process unloads the lower limbs by 72%, resulting in only one-third of the body weight being transmitted to the ground (Harrison and Bulstrode, 1987). Immersion to the anterior iliac produced a percentage weight bearing of 47%. Therefore, it is plausible that differences between waist and chest immersion could alter the metabolic demands of exercise in water because buoyancy supports the body weight and reduces postural muscle activity (Sugajimo et al., 1996).

At 4.5 and 5.5 km·h^{-1} $\dot{V}O_2$, $\dot{V}_E$, $\dot{V}CO_2$ were significantly higher in water at both temperatures than on land. These findings are in agreement with others ((Bryne et al., 1996, Gleim and Nicholas, 1989). The energy cost of increasing speed by 1 km·h^{-1} was approximately 20% on land and 52% in water. Bryne et al. (1996) reported similar results for this speed range and Gleim and Nicholas (1989) noted that this effect was non-linear with the steepest increases in $\dot{V}O_2$ occurring between 2.4 and 5.6 km·h^{-1}. Whilst the data presented here cannot confirm the work of Gleim and Nicholas the pilot studies support the non-linear response in that walking in water was limited, in this sample, to approximately 5.5 km·h^{-1}, after which subjects were forced to run. As running in waist-deep water reduces the energy costs the slope of the curve would flatten as subjects changed from a walk to a run. Clinicians should be aware that, for the same energy cost increase, walking speed in chest-deep water should be half that on land. Furthermore, increasing running speed in chest deep water has a negligible effect on energy expenditure compared to similar increases on land.

The increased energy costs of walking in water at 4.5 and 5.5 km·h^{-1} are reflected by the greater RPE-legs scores in water than on land. Brown et al. (1996) noted similar findings during deep water running. At 5.5 km·h^{-1} perceived exertion for both legs and breathing was greater in water than on land which suggests that the resistance of the water was challenging both peripheral and central competence. Given that RPE-legs scores were higher than RPE-breathing it is likely that muscle fatigue was the limiting factor rather than cardiovascular. Studies on water treadmills have not considered perceived exertion and those on deep water running have considered the relationship of RPE and $\dot{V}O_2$. In this study the RPE-legs – $\dot{V}O_2$ relationship was similar between land and water. During deep water running perceived effort has been shown to be either similar (DeMaere and Ruby, 1997;

Gehring et al., 1997) or higher in water (Michaud et al., 1995b; Svedenhag and Seger, 1992) with the differences thought to be related to subject familiarity. Whilst the subjects in this study did not use water treadmill walking as a training aid a pilot study which focused on subjects' perception of a comfortable and reliable technique showed that 3 training sessions of 10 minutes duration was required. Therefore it would appear from the RPE-legs – $\dot{V}O_2$ data that the familiarization period was satisfactory. Given the similarity of RPE-$\dot{V}O_2$ relationship between land and water treadmill walking as seen in this study prescribing and monitoring exercise intensity from land-based RPE values would be accurate in water. However, the external validity of these results is limited to healthy subjects who have undergone familiarization training.

Whilst cadence increased with speed on land and water treadmills, it was approximately 27 strides·min^{-1} less in water. A reduced cadence has been noted in shallow water running and deep water running studies but has not been previously reported during water treadmill activity (Frangolias and Rhodes, 1995; Town and Bradley, 1991). Town and Bradley reported that shallow water running and deep water running yielded approximately a 32% and 47.5% reduction in cadence respectively. The results presented here represent a 30% decrease and may be attributed to the resistance of the water which makes it difficult to generate the limb speeds observed on land. This implies longer contraction times which may result in rhythmic ischaemia with consequent reduced oxygen delivery and greater reliance on anaerobic pathways. However, similar $\dot{V}_E$-$\dot{V}O_2$ relationships and RER values between land and water suggest similar metabolic pathways were being used to fuel the exercise. At 5.5km·h^{-1} subjects were exercising at approximately 60% of predictive maximal HR which equates to approximately 42% $\dot{V}O_{2\,max}$ and this low exercise intensity in a healthy group of subjects suggests that aerobic pathways predominated.

5.4.2. Effects of Temperature

Resting BP was unaffected during immersion in water, both at 28.2°C and 35.8°C. This confirms Epstein's conclusions (1992) but contradicts others (Sramek et al., 2000; Weston et al., 1987). After exercise in water SBP was significantly higher than on land. Furthermore SBP after exercise in water at 35.8°C was greater than in water at 28.2°C. Given the change scores between land and water, which were greater than 17mmHg, it would appear to be a true effect rather than measurement error. Little data on BP responses to exercise in water have been reported, perhaps because of the technical difficulties. These are less of a problem during the relatively static position of cycle ergometry but no differences in either SBP or DBP were noted between land and water (Hanna et al., 1993; Sheldahl et al., 1992 and 1987; Christie et al., 1990; Connelly et al., 1990). The differences between studies may be explained on the basis of muscle mass activated in that it is known that SBP rises more during arm than leg exercise (Astrand and Rodahl, 1986). Cycle ergometry is limited to the large muscles of the lower limbs whereas water treadmill walking includes leg and arm activity throughout a larger range of motion against the resistance of the water. However, this explanation overlooks the effects of temperature given that SBP after exercise in water at 35.8°C was greater than that in 28.2°C. Whether this is an immediate post-exercise phenomena or persists during exercise cannot be deduced from the present data but if confirmed may have implications for patients with cardiovascular dysfunction, even though BP returned to normal within 5 minutes of the end of exercise.

At 3.5km·h^{-1} HR was significantly lower in water at 28.2°C than at 35.8°C or on land. A lower HR in water has been reported during resting head-out water immersion in water below thermoneutral (34.5-35°C) and occurs because the peripheral vasoconstriction augments central blood volume which increase stroke volume and via baroreceptor stimulation results in a reflex bradycardia (Weston et al., 1987; Rennie et al., 1971; Craig and Dvorak, 1966). During exercise in water below thermoneutral (17-34°C) HR may be similar or lower depending on the exercise intensity, mode of exercise and muscle mass activated (Gehring et al., 1997; DeMaere and Ruby, 1997; Michaud et al., 1995; Sheldahl et al., 1992 and 1987; Svedenhag and Seger, 1992; Ritchie and Hopkins, 1991; Christie et al., 1990; Connelly et al., 1990). Previous studies on water treadmill exercise have shown that, at 3.5 km·h^{-1} HR is similar to land (Bryne et al., 1996; Napoletan and Hicks, 1995; Gleim and Nicholas, 1989). However, these studies used higher water temperatures between 30.5 and 32°C and therefore the degree of peripheral vasoconstriction may have been less. In support of this, walking at 3.5 km·h^{-1} in water at 35.8°C yielded similar HR to land. However, future studies which include specific measures of stroke volume would clarify the effects of peripheral vasoconstriction on the central blood volume. A second explanation might be the differences between subject familiarization. The large inter-subject HR variability noted by Yamaji et al. (1990) during deep water running and their observation that novice subjects used their arms more than familiarized subjects suggests that familiarity is an important determinant of the HR response. In the present study subjects underwent a standardized familiarization period and therefore may have used their arms less than in the other studies. Given that arm work results in greater increase in HR than leg work of similar intensity this is an appealing hypothesis which is supported by the HR results at increasing speeds. In this study HR in water at 28.2°C was similar to land as speed increased. In other studies, for the same depth, HR was higher in water than on land as walking speed increased (Bryne et al., 1996; Gleim and Nicholas, 1989). Therefore, the HR response to water treadmill walking in thermoneutral (for exercise) water depends on the water temperature and muscle mass activation as a function of task familiarity.

In water at 35.8°C HR was similar to land at 3.5 $km{\cdot}h^{-1}$ and higher at 4.5 and 5.5 $km{\cdot}h^{-1}$. These results are consistent with those of Gleim and Nicholas (1989) who reported significantly higher HR in water at 36°C than on land with increasing speed and suggested that the effects of the hypervolamia are overcome by the thermal stimulus to increase HR. Because of thermoregulatory concerns few studies have considered exercise at temperatures above exercising thermoneutral. Nevertheless, Weston et al. (1987) give some valuable insights on the effect of resting water immersion at 37°C. During 15 minutes of immersion at 37°C Weston noted a tachycardia and an increase in core body temperature of 0.5°C. Thus the observations reported here of higher HR during exercise in water at 35.8°C would be consistent with this effect at rest. Weston et al (1987) speculated that the most important contribution to the tachycardia was increased rate of sino-atrial node depolarisation which occurs at higher core temperatures. After exercise in water at 35.8°C a 0.65°C rise in oral temperature was noted which is likely to have had a direct effect on sino-atrial discharge, increasing HR.

In contrast to Gleim and Nicholas (1989), who demonstrated higher HR for a given $\dot{V}O_2$, the present study noted that the HR-$\dot{V}O_2$ relationship was similar between land and water at 35.8°C. Gleim and Nicholas (1989) showed that the relationship was most apparent at higher exercise intensities ($\dot{V}O_2$ = 30 ml·kg^{-1}·min^{-1}). Given the maximum exercise intensity of this study was 22 ml·kg^{-1}·min^{-1} an effect may have been missed. The HR-$\dot{V}O_2$ relationship in chest deep water at 28.2°C was significantly lower than on land. Once again Gleim and Nicholas (1989) reported higher HR for a given $\dot{V}O_2$ in waist deep water at 30°C. This disparity highlights the differences in cardiorespiratory responses as a result of water temperature and depth. Subject familiarity may also have affected the HR. Based on the present results land based HR values of exercise intensity would overestimate metabolic requirements in water. Studies on deep water running (in water < 30°C) share conflicting results in terms of HR-$\dot{V}O_2$ relationship. Some show HR to be similar (Gehring et al., 1997; DeMaere and Ruby, 1997; Michaud et al., 1995) and others lower by 10-17 beats·min^{-1} for a given $\dot{V}O_2$ (Svedenhag and Seger, 1992; Ritchie and Hopkins, 1991). The differences have been attributed to the water temperature with the lower temperatures giving the lower HR and subject familiarity. At present, the use of HR values obtained on land to prescribe and monitor exercise intensity on water treadmills is unreliable. Future research should examine the interaction between exercise intensity, exercise mode, muscle mass activation, water depth and temperature and subject familiarity on the HR-$\dot{V}O_2$ relationship.

5.5. CONCLUSIONS

This study has shown that the metabolic costs of treadmill walking in water are greater than comparable land exercise above walking speeds of 4.5 km·h^{-1}. Below this speed energy costs were similar showing that the opposing effects of buoyancy and resistance have a profound effect on metabolic demand in water. The resistance of the water at 5.5 km·h^{-1} challenged the leg muscles more than the cardiovascular system and was the limiting factor to further increases in walking velocity. Clinicians should be aware that increasing walking speed by 1 km·h^{-1} in water doubles the energy costs compared to land and therefore speed increments should proceed cautiously, especially in elderly or chronically ill populations. The increase in SBP in water was unexpected and requires further examination during, as opposed to after, the exercise test. The greatest increases in SBP arose after exercise in water at 35.8°C and may vindicate this researcher's concern over the use of hospital hydrotherapy pools for cardiovascular conditioning. Whether these results would be replicated in different populations cannot be elucidated from the present results and provides a further avenue for research.

In water at 35.8°C the HR-$\dot{V}O_2$ relationship was similar between land and water and so the use of land-based HR values would be valid to prescribe and monitor exercise intensity in water. However, in water at 28.2°C HR was lower for a given $\dot{V}O_2$ and therefore land-based HR would overestimate metabolic demand. Despite the limitations of HR as a useful indicator of exercise intensity in water the subjects in this study were able to exercise within the HR ranges accepted by the ACSM as necessary for an aerobic training effect. However, the training stimulus was low and therefore walking at 5.5km·h^{-1} for the recommended frequency and duration may improve aerobic capacity in the less fit subjects only. Challenging the fitter subjects would require faster walking speeds if the leg musculature was strong enough to overcome the water resistance or could be achieved through reduced water depths, although this has the disadvantage of increasing ground reaction force. Nevertheless, it has been shown that a cardiorespiratory stimulus is possible in normal healthy females. Given the difficulties experienced by patients with RA extrapolating these results to the RA population would be speculative at best and erroneous at worst.

CHAPTER 6

CARDIORESPIRATORY RESPONSES TO WATER

AND

LAND TREADMILL WALKING

IN

PATIENTS WITH RA

6.1. INTRODUCTION

In Chapter 4 it was hypothesized that the benefits experienced following hydrotherapy may have been related to small increases in aerobic capacity, given the deconditioned status of RA patients and the physical properties of the water. However it was recognized that the opposing effects of buoyancy and viscosity on energy expenditure could challenge this hypothesis. The results from Chapter 5 on normal women tend to support this. Chapter 5 showed that at walking speeds of 5.5 $km \cdot h^{-1}$ the factor limiting cardiovascular responses was peripheral fatigue, resulting from the resistance to movement in water. The exercise intensity was low, even at the highest walking speed, and therefore a training effect may only be apparent in those with poor cardiorespiratory fitness. Given the reduced muscle strength of patients with RA it cannot be assumed that this population would be able to walk in water at the speeds of normals and may therefore fail to challenge the aerobic system. Furthermore, the HR-$\dot{V}O_2$ relationship may be altered depending on the water temperature and subject status (ie, initial physical fitness and task familiarity). Therefore, in order to ascertain the feasibility of hydrotherapy in stimulating an aerobic response, and for accurate prescription purposes, a walking test in water for patients with RA is merited.

The purpose of this study was to compare the relationships between HR, $\dot{V}O_2$ and RPE, with speed during land and water treadmill walking in patients with RA. A second hypothesis was tested to determine the threshold for inducing cardiorespiratory training effects because of the uncertainty whether patients with RA would be able to generate sufficient speed to invoke sufficient intensity given that the resistance to movement increases with the speed of walking. Evidence to support this hypothesis would be useful to hydrotherapists who wish to incorporate an effective aerobic component into their programmes. Furthermore, it was hypothesised that walking in water would demand greater energy expenditure but produce less pain (due to the warmth of the water and the buoyancy mediated reduction in joint loading) than walking at similar speed on land. Prior to testing these hypotheses a pilot study was conducted to examine the maximum speed at which patients with RA could walk in the water treadmill.

6.2. PILOT STUDY – TREADMILL SPEED SELECTION

Given the reduced muscle strength of patients with RA and their altered gait patterns (Sakauchi et al., 2001) it was considered unlikely that patients would be able to walk at the speeds used in the previous study. Therefore, 5 female patients with RA, mean age of 50.7 years (SD±6.9), mean disease duration of 3.9 years (SD±1.3) and in Functional Class 2 participated in a pilot study to investigate the maximum walking speed which could be maintained for at least 5 minutes. Following the familiarisation period established in the previous study, patients performed an incremental walking test, starting at 1 $km \cdot h^{-1}$ and increasing by 1 $km \cdot h^{-1}$ every 5 minutes until patients requested to stop or began to run. Patients were immersed in chest deep water at 34.5°C. All patients could walk comfortably and with good technique up to 4 $km \cdot h^{-1}$ on the water treadmill. Most could walk/jog at 5 $km \cdot h^{-1}$ but 3 complained of lower limb joint pain before the end of the 5 minute bout. Therefore it was decided to limit the maximum speed to 4.5 $km \cdot h^{-1}$ and so, following the pattern of the earlier study, patients walked at 2.5, 3.5 and 4.5 $km \cdot h^{-1}$ on both water and land treadmills.

6.3. METHODOLOGY

6.3.1. Subjects

The sample size was calculated using data from the previous study on normal females. Using the 0.5 l·min^{-1} difference between land and water treadmill $\dot{V}O_2$ at 5.5 km·h^{-1}, power of 80% and alpha of 0.05 fifteen patients were deemed necessary to observe a significant difference between land and water treadmill walking if it was present.

Fifteen female patients, aged 30-60 years, with Functional Class I or II RA (Hochberg et al., 1992) and with a disease duration of equal to or less than 5 years were recruited from the Royal National Hospital for Rheumatic Diseases, Bath. Patients with early disease were chosen to ensure completion of all the tasks required. Patients were excluded if they walked with an aid, had undergone lower limb surgery within the past 3 months, had undergone hip, knee or ankle arthroplasty or were experiencing a flare of their RA. Additionally, patients with comorbid cardiovascular disease, based on patient report and medical notes scrutiny, were excluded.

Suitable patients were identified from the database at the Royal National Hospital for Rheumatic Diseases, Bath and following consultation of their medical notes sixty-five letters, inviting patients to participate in the study. Forty-three patients (66%) replied, 22 of whom were eager to participate and 21 who refused. Where reasons for refusal were given 4 patients pointed out that their disease duration was longer than the 5 years specified (one lady was wheelchair-bound !) and difficulties with time off work, dislike of water, comorbidity (chemotherapy, eczema), transport and childcare problems were also cited. Of the 22 patients who agreed to participate 3 patients declined to attend after a telephone conversation in which the protocol was explained in detail (due to transport/time difficulties) and one was found to be unsuitable (recent undiagnosed shortness of breath coupled with known hypertension). Eighteen patients attended for initial assessment. Two of these patients were refused entry on clinical grounds (one had recently diagnosed fibromyalgia and the other appeared to be starting a flare) and one never turned up for the subsequent visits. Therefore, 15 patients completed the study.

Ethical approval for the study was granted by the local regional ethical committee and patients completed written consent forms before participating in the study (Appendix 5.3).

4.3.2. Protocol

At an initial visit patients' past and current medical history were documented using a health screening questionnaire and interview, similar to that used in Chapter 5 (Appendix 6.1 and 6.2). Details regarding disease duration, level of physical activity (using the Allied Dunbar National Fitness Survey scoring system), height, weight, heart rate, BP, medication, and joint tenderness, using the Ritchie articular index (Thompson et al., 1991) were recorded. Disease status and pain were recorded using the Health Assessment Questionnaire (Fries et al., 1980) and short form McGill Pain Questionnaire (Skevington, 1979). Patients then underwent the familiarisation training as explained in Chapter 5. Some patients were able to master breathing using the open-circuit spirometry set-up at this visit. However, the majority of patients required one further session to practice this technique whilst walking.

Two walking tests, randomly allocated, were completed in the water and on the land treadmills. Each test was performed at the same time of day, separated by at least 48 hours and involved a similar procedure. After a 2 minute warm-up at 1.5 $km \cdot h^{-1}$ patients completed 3 consecutive bouts of 5 minutes duration at progressively increasing speeds (2.5, 3.5 and 4.5 $km \cdot h^{-1}$). Water depth was to the level of the xiphoid process and the water was maintained at 34.5^0C as recently recommended by the Hydrotherapy Association of Chartered Physiotherapists as the optimal pool temperature for hospital hydrotherapy pools (HACP standards for good practice). Patients were 2 hours post-prandial and refrained from smoking and caffeine intake 2 hours before the test began. The air temperature of the laboratory averaged 26^0C ($\pm 2.1^0C$) and the humidity 50% (±4.8%).

6.3.3. Measurements

Measures of expired gas, HR, BP, RPE and oral temperature were collected in a manner similar to that in Chapter 5 (Appendix 6.3). Additionally, pain, using a 10cm visual analogue and knee range of movement, measured as in Chapter 4 were recorded at the beginning and end of each test.

Calibration checks for the treadmill and gas analysers were performed as before.

6.3.4. Statistics

Exploratory data analysis, including examination of descriptive statistics for outliers, skewness and kurtosis and completion of the Kolmogorov-Smirnov test for checking the assumption of normality of distribution were performed. A two-way ANOVA with repeated measures was used to examine differences between land and water walking and speed. When significant F values of $p \leq 0.05$ were found post-hoc testing using paired t-tests with a Bonferroni correction factor were employed to isolate the significant differences (Kinnear and Gray, 1999; Lang and Secic,1997; Godfrey, 1985). The Friedman test was used to examine differences in the RPE data. This was followed up by the Wilcoxen test (and Bonferroni correction factor) when an overall significant p value was observed. Pre- to post-test data (eg: BP, knee range of movement and oral temperature) was analysed using paired t-tests or the Wilcoxen test in the case of non-parametric data (eg: pain). Differences between relationships (eg: HR-$\dot{V}O_2$ relationship) were tested using a paired t-test after a simple linear regression model estimated the dependent variable, for a given level of the independent, and tests for normality of the response variable were satisfactory. All values are expressed as mean ± SD. Data was analysed using SPSS for Windows, version 10.

6.4. RESULTS

Fifteen female patients with an average age of 47 years (±8.05) and a disease duration of 3.1 years (±1.3) completed the study. Fourteen patients belonged to Functional Class II and one to Class I. Levels of habitual physical activity were low (median =1, range = 1-3) as assessed by the Allied Dunbar National Fitness Survey (1992). Resting HR, taken before rising in the morning averaged 71.3 (±8.6) beats·min^{-1} and standing blood pressure was 118.8/84 mmHg. Four patients smoked (range 3-20 per day), and 3 had asthma, controlled by inhalers. One patient took thyroxine for hypothyroidism. All patients were on disease modifying anti-rheumatic drugs and anti-inflammatories, the dose of which remained unchanged during the study. Table 6.1 shows other important sample characteristics.

Table 6.1 - Sample Characteristics (EMS = early morning stiffness. MPQ = McGill Pain Questionnaire. IQR = inter-quartile range).

	EMS (mins)	**HAQ**	**Ritchie Index**	**Pain (VAS)**	**MPQ Sensory pain**	**MPQ Evaluative/affective pain**
Median	5	0.125	8	1.1		
IQR	0-30	0-1.625	2-28	0.1-3.9		
Mean ± SD					2.83 (0.5)	0.25 (0.2)

Figures 6.1-6.3 show the relationships between $\dot{V}O_2$, $\dot{V}_E$ and $\dot{V}CO_2$ respectively and treadmill speed (2.5, 3.5 and 4.5 km·h^{-1}) for land and water treadmill exercise. As speed increased $\dot{V}O_2$, $\dot{V}_E$ and $\dot{V}CO_2$ increased on both land and water treadmills (P<0.001). In each case water treadmill responses were lower than land for $\dot{V}O_2$, $\dot{V}_E$ and $\dot{V}CO_2$ at 2.5 and 3.5 km·h^{-1} (P<0.005). At 4.5 km·h^{-1} there was no difference between $\dot{V}O_2$, $\dot{V}_E$ and $\dot{V}CO_2$ between the two conditions, as the response to water treadmill exercise increased to equate to that on land. Figure 6.4 shows the $\dot{V}_E$-$\dot{V}O_2$ relationship, the range of which is extended during water treadmill exercise. $\dot{V}_E$ did not differ significantly in water for a given $\dot{V}O_2$. During land treadmill walking the expected linear relationship between VE and $\dot{V}O_2$ is seen. On land the RER increased with speed (P<0.01). In water the RER was similar at 2.5

and 3.5 km·h^{-1} but increased significantly at 4.5 km·h^{-1}. No significant differences in RER were observed between land and water treadmills (Table 6.2).

HR increased significantly on land and in water as speed increased (P<0.001). On land, HR increased linearly but in water showed a significant interaction effect (Fig 6.5). At 2.5 km·h^{-1} HR was significantly lower in water than on land, similar at 3.5 km·h^{-1} and higher at 4.5 km·h^{-1} (P<0.001, NS and 0.001 respectively). Figure 6.6 shows the relationship between HR and $\dot{V}O_2$ during land and water treadmill exercise. For the same speeds the range of response is extended in water and the line is shifted to the left. Thus, for a $\dot{V}O_2$ of approximately 0.74l.min^{-1} HR was 9 beats·min^{-1} higher in water than on land (P<0.002). Conversely, land-based HR overestimates water $\dot{V}O_2$ by approximately 15%.

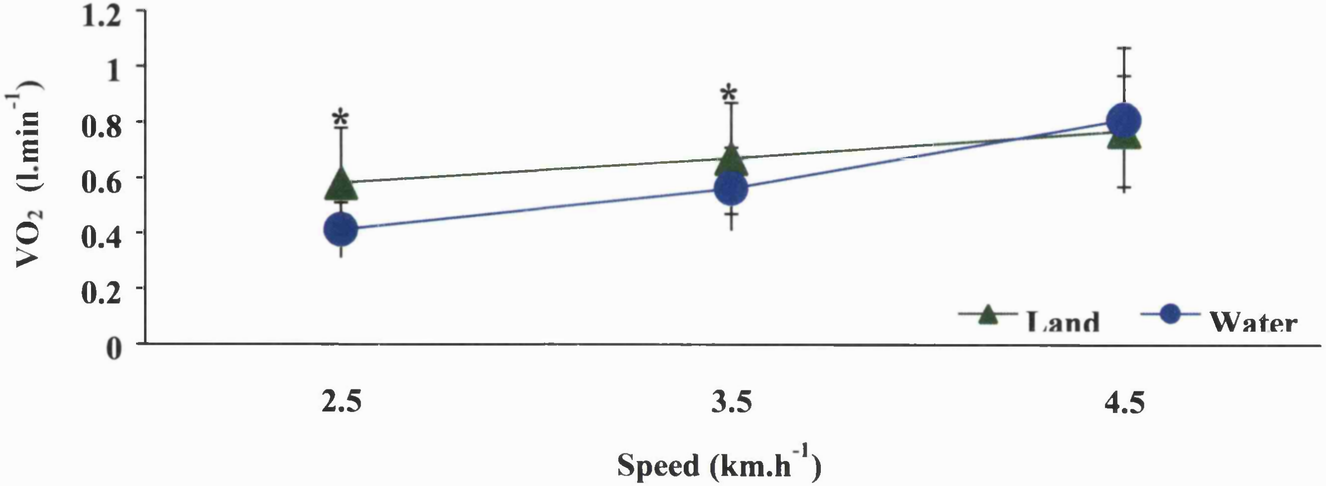
Systolic blood pressure increased significantly with exercise on land and in water (t = -5.7 and –5.3 respectively, df=14; P=0.001) but was unaffected by water immersion (Table 6). Diastolic blood pressure was significantly reduced by water immersion (t=3.4, df=14; P=0.004) but was not affected by exercise. Consequently mean arterial pressure was lower during upright rest in water (t=3.8, df=14; P=0.002). No significant differences in MAP change were noted between land and water. Pulse pressure increased significantly with exercise on land and in water (t = -6.2 and 6.8 respectively, df=14, P=0.001) but was not affected by water immersion.

A significant increase in RPE-legs with speed was observed during land and water treadmill walking (P<0.001) (Fig 6.7). At 2.5 km·h^{-1} RPE-legs was similar between land and water conditions. Above this speed the perception of effort was significantly greater in water than on land (P<0.012). Figure 6.8 shows the relationship between RPE-legs and $\dot{V}O_2$ shows that RPE is higher for a given $\dot{V}O_2$ in water by approximately 15-20% (P<0.02). For example, a RPE-legs rating of 12 gave rise to a $\dot{V}O_2$ of 0.76 l·min^{-1} on land and 0.62 l·min^{-1} in water. Table 6.2 presents the results for RPE-breathing as a function of speed. RPE-breathing increased with speed during land and water treadmill walking (P <0.001). However no significant differences in RPE-breathing were observed between land and water exercise.

Figure 6.9 shows that cadence increased significantly with speed during land and water treadmill walking (P<0.001). However, at all speeds, stride frequency was approximately 21.9 strides·min^{-1} lower in water than land (P<0.001). Therefore, at 4.5 km·h^{-1} the O_2 cost per stride was significantly higher in water than on land (P<0.001) (Table 6.2).

After exercise in water oral temperature increased by 0.37°C. This was significantly greater than on land (t=3.5, df=13; P=0.004). Pain did not increase with exercise and was similar between land and water treadmills. Similarly, knee range of movement was not affected by exercise in either treadmill. Table 6.4 presents these results.

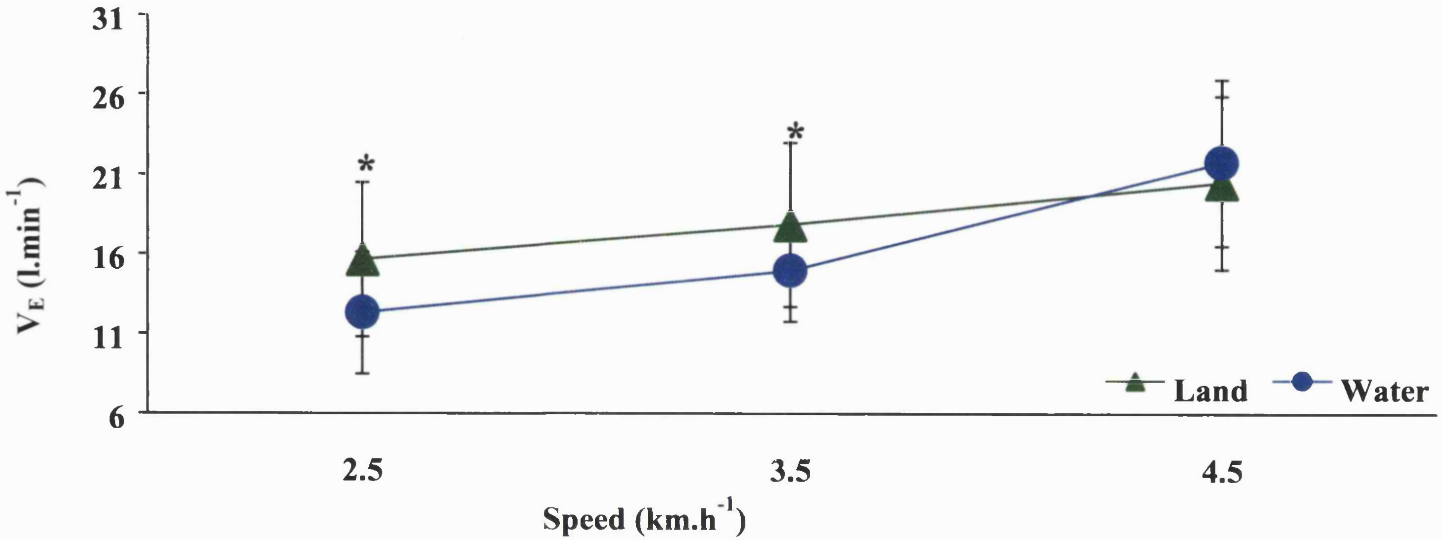
Figure 6.1 - VO_2 during land and water treadmill walking



As speed increased on land and in water VO_2 increased (P<0.001).

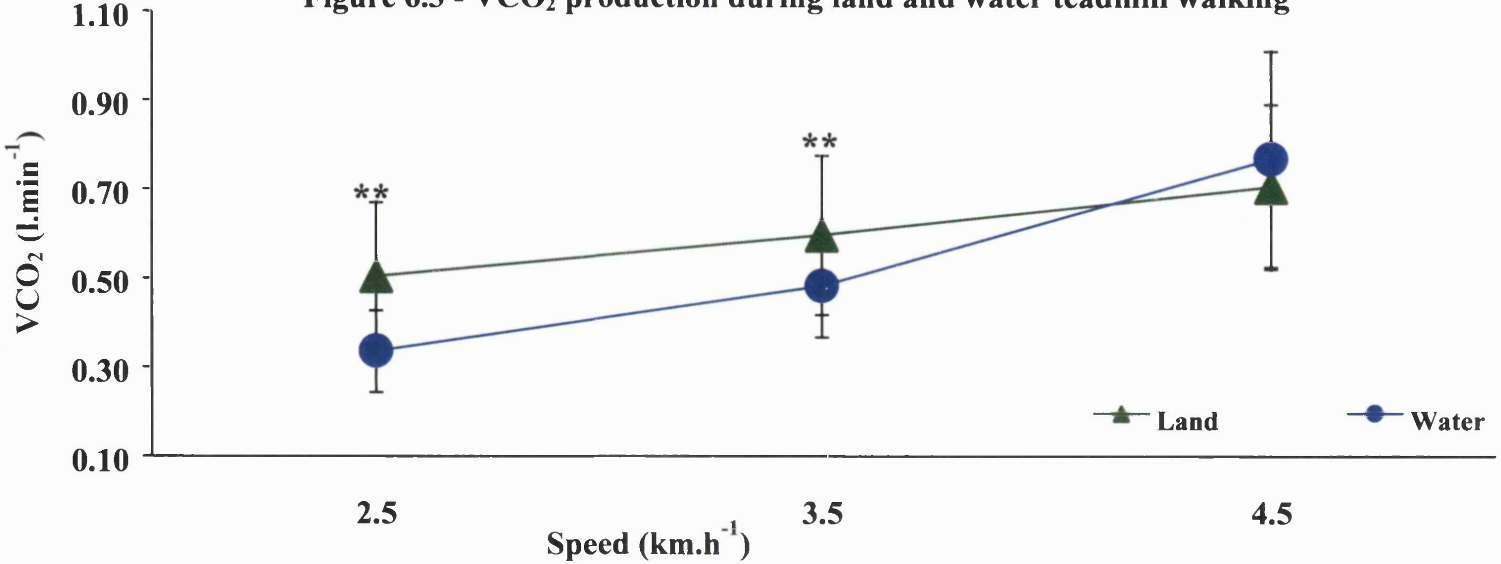
* P<0.01 - VO_2 was significantly lower in water.

Figure 6.2 - V_E during land and water treadmill walking



As speed increased on land and water V_E increased significantly. (P=0.001). *P<0.01 - V_E was significantly lower in water.

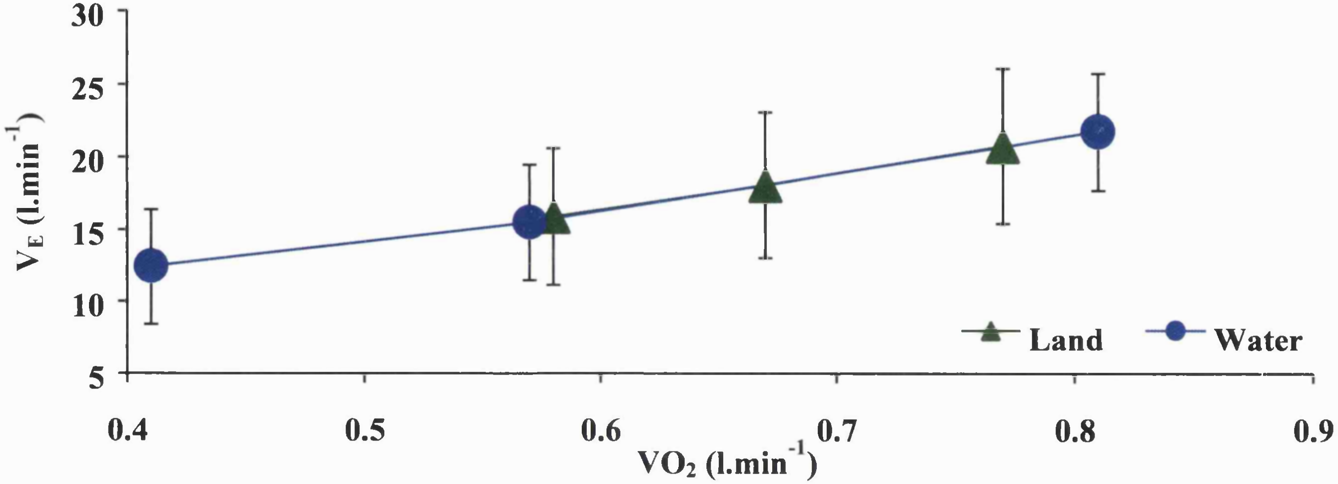
Figure 6.3 - VCO_2 production during land and water teadmill walking



As speed increased on land and water VCO_2 production increased significantly ($P<0.001$).

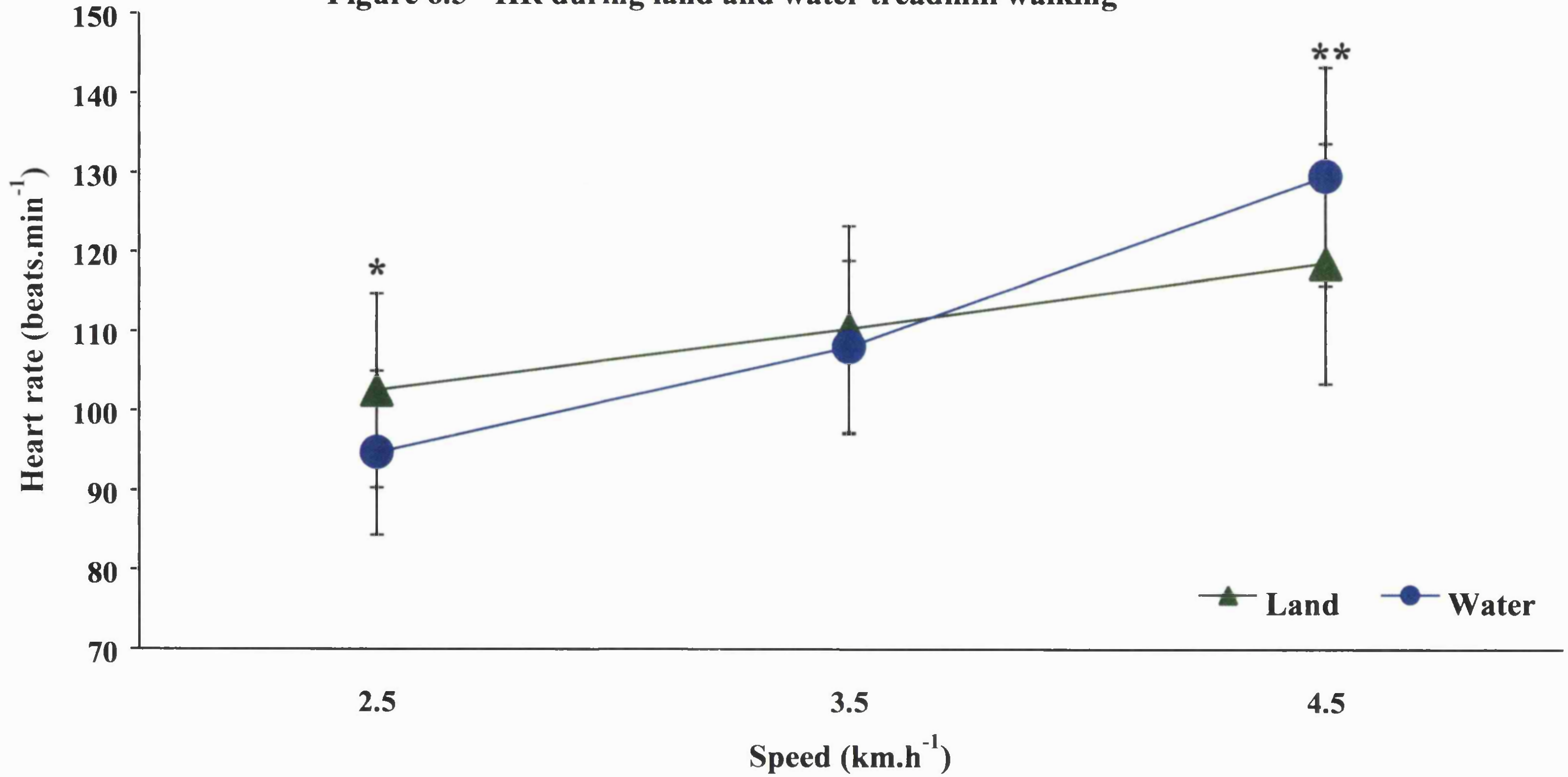
* *$P<0.001$ - VCO_2 production was lower in water than on land.

Figure 6.4 - V_E:VO_2 relationship during land and water treadmill walking



V_E did not differ significantly in water and on land for a given VO_2. However the range is extended in water and there is a greater percentage increase in V_E relative to VO_2, especially at 4.5 km.h^{-1}.

Figure 6.5 - HR during land and water treadmill walking

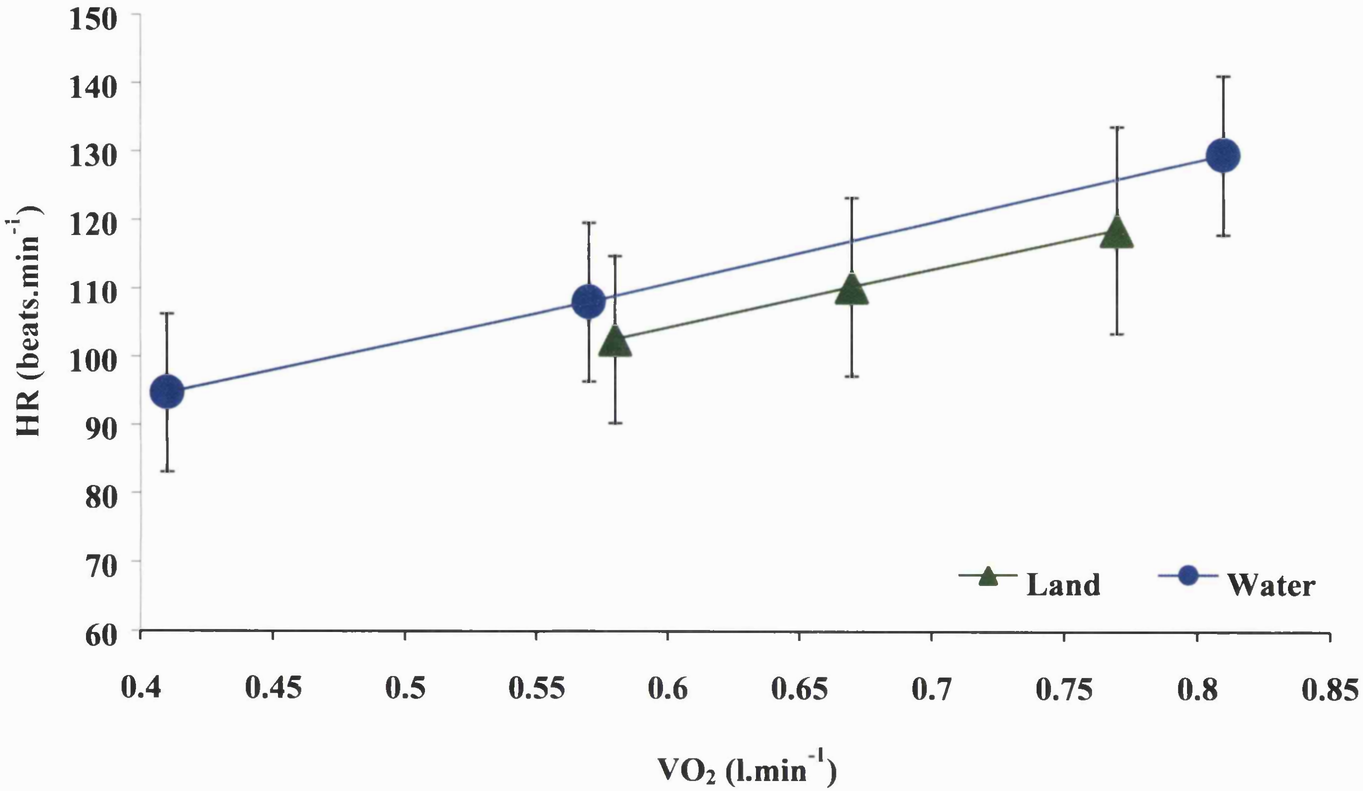


As speed increased on land and water HR increased significantly (*P*<0.001).

* p<0.01 - HR was lower in water than on land.

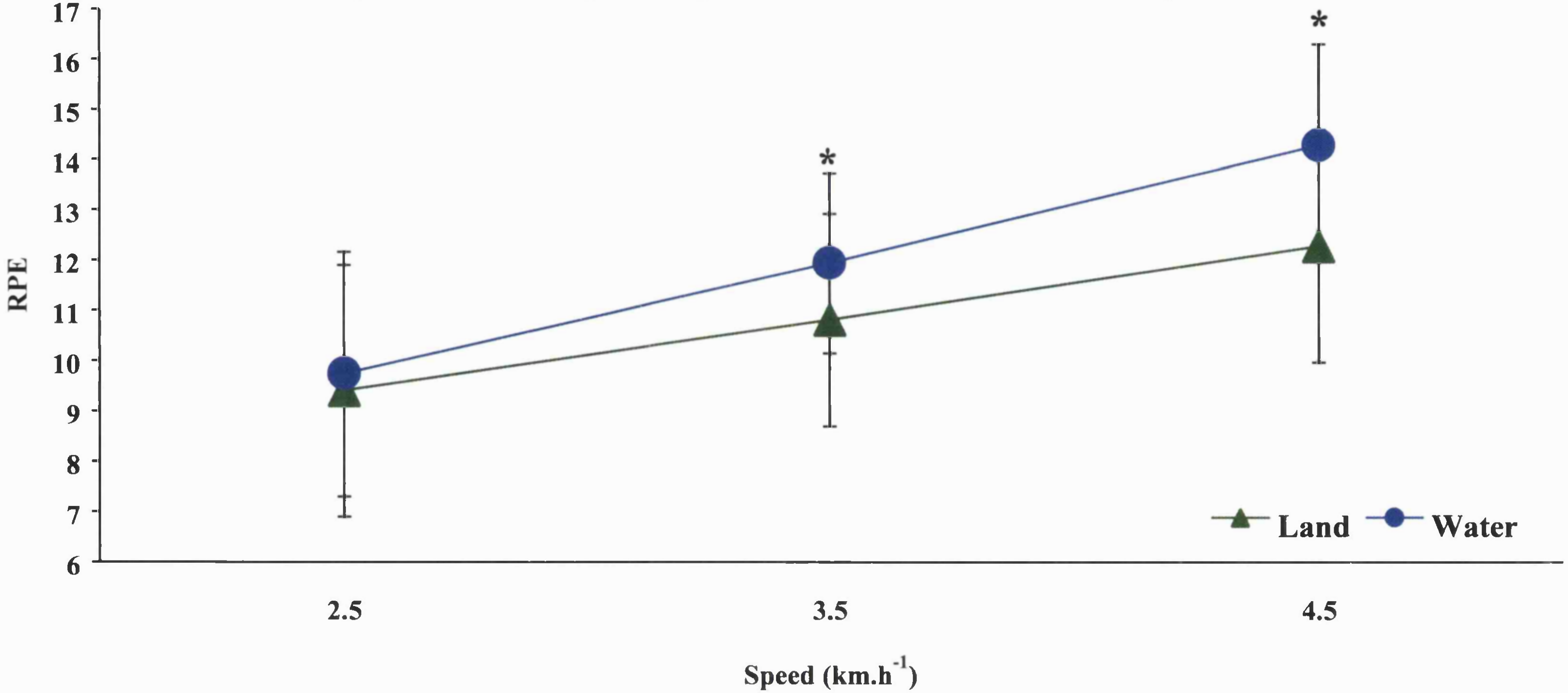
** p<0.001 - HR was higher in water than on land.

Figure 6.6 - HR-VO_2 relationship



HR was significantly higher in water than on land for a given VO_2 ($P<0.003$).

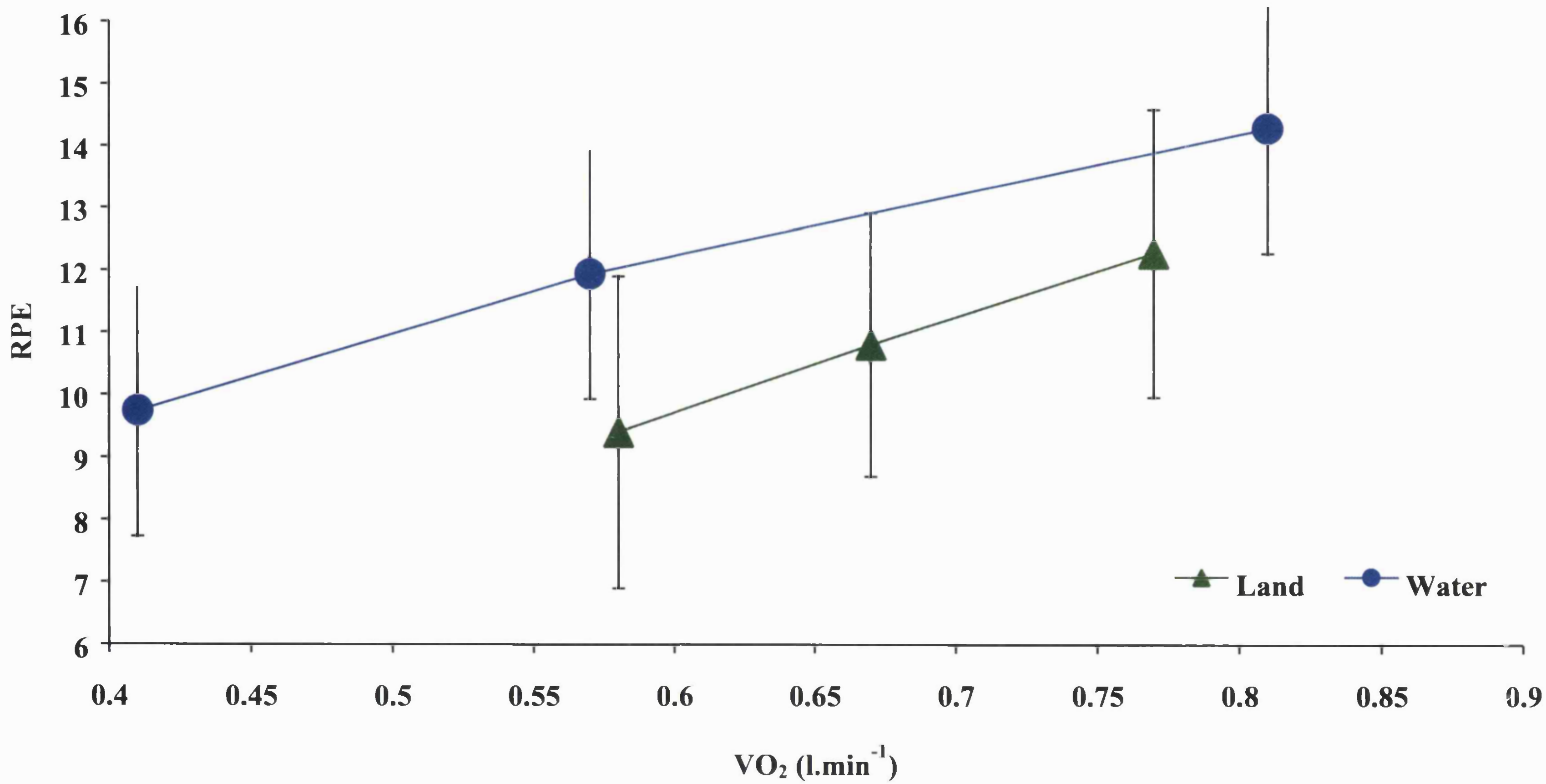
Figure 6.7 - RPE-legs during land and water treadmill walking



As speed increased on land and in water RPE-legs increased (P<0.05).

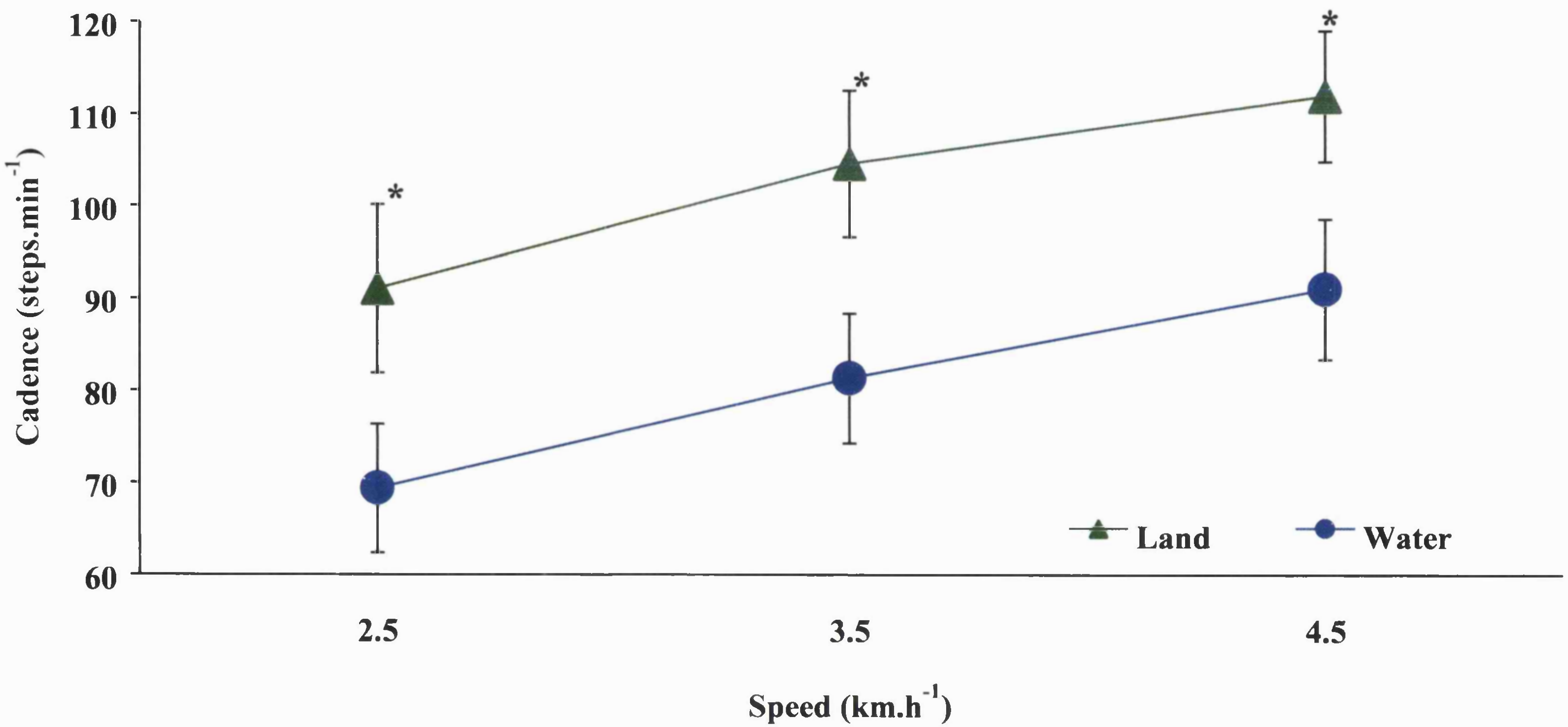
* P<0.05 - RPE-legs was significantly higher in water.

Figure 6.8 - RPE-legs - VO_2 relationship



RPE is approximately 15-20% higher in water than on land during treadmill walking (P<0.02).

Figure 6.9 - Cadence during land and water treadmill walking



As speed increased on land and in water cadence increased (P<0.001).

*** P<0.001 - cadence was significantly greater in water than on land.

Table 6.2 - means and (±SD) for respiratory exchange ratio (RER), ratings of perceived exertion for breathing (RPE) and oxygen cost per stride ($\dot{V}O_2$/str : mls·min^{-1}).

	WATER			LAND		
Variable	**Speed (km·h^{-1})**					
	2.5	3.5	4.5	2.5	3.5	4.5
RER	0.83 (0.1)	0.86 (0.1)	0.95 ** (0.08)	0.86 (0.07)	0.9* (0.07)	0.92** (0.07)
RPE-breathing	8.87 (1.6)	10.9* (1.6)	12.8** (2.1)	8.87 (2)	10.4* (1.9)	11.53* *(2)
$\dot{V}O_2$**/str**	5.9 (1.5)	7.04* (2)	8.9**^ (2.9)	6.45 (2.1)	6.42 (1.9)	6.92** (1.9)

* 3.5 km·h^{-1} is significantly greater than 2.5 km·h^{-1} within conditions (P<0.05).

** 4.5 km·h^{-1} is significantly greater than 2.5 and 3.5 km·h^{-1} within conditions (P<0.05).

^ The $\dot{V}O_2$/stride is greater in water than on land at 4.5km.h^{-1} (P< 0.001).

Table 6.3 – Mean (±SD) systolic and diastolic blood pressure, mean arterial pressure and pulse pressure before exercise, resting in water before exercise and immediately after exercise on land and in water (mmHG).

	Land	**Water**
Systolic BP		
Before exercise – standing on land	113.33 (15.6)	116.7 (15.5)
Before exercise – standing in water		113 (16)
After exercise	129.6 (18.3)*	126 (13.6)*
Diastolic BP		
Before exercise – standing on land	79.3 (11.8)	81.3 (9)
Before exercise – standing in water		71.2 (13.3)**
After exercise	80.5 (11.7)	67.6 (10.8)
Mean Arterial Pressure		
Before exercise – standing on land	90.7 (12.5)	93.1 (10.3)
Before exercise – standing in water		85.1 (11.5)^
After exercise	96.9 (12.9)	87.1 (8.4)
Pulse pressure		
Before exercise – standing on land	34 (8.6)	35.3 (11.2)
Before exercise – standing in water		41.8 (17.9)
After exercise	49.1 (12.4)^^	58.4 (17.6)^^

*Systolic blood pressure increased significantly with exercise whether on land or in water (t = -5.7 and –5.3 respectively, df=14, p=0.001).

**Diastolic blood pressure was significantly reduced by water immersion (t=3.4, df=14, p=0.004).

^ Mean arterial pressure was significantly reduced by water immersion (t=3.8, df=14, p=0.002).

^^ Pulse pressure increased significantly with exercise on land and in water (t = -6.2 and 6.8 respectively, df=14, p=0.001).

Table 6.4 - Oral temperature, pain and knee range of movement (right and left knees have been summed) before and after land and water treadmill walking. The mean and SD are shown, except for pain, which is represented by the median and range.

	LAND		**WATER**	
	Pre	**Post**	**Pre**	**Post**
Oral temperature(°C)	36.5 (0.3)	36.4 (0.4)	36.6 (0.3)	36.9 (0.4)
Pain (VAS)	0.9 (2.2)	1.3 (2.3)	1 (1.6)	1 (1.2)
Knee ROM (°)	264.7 (23)	265.5 (22)	271 (23)	271.6 (20)

6.5. DISCUSSION

The HR-$\dot{V}O_2$ relationship showed that HR was higher by approximately 9 beats·min^{-1} for a given $\dot{V}O_2$ in water than on land. The water temperature was 34.5°C, the accepted temperature for hydrotherapy pools but 0.5°C above that regarded as thermoneutral for exercise in water. In water sublingual temperature increased significantly by 0.37°C and so it is possible that a greater thermal load may have caused a greater HR in water. A more appealing explanation may be related to muscle fibre recruitment in that the unfamiliar biomechanical demands of walking against the resistance of water is considered to alter muscle activation and favour Type II fibre recruitment. Consequently, increased metabolic activation of the chemoreceptors in the active muscles would augment sympathetic nervous stimulation and hence HR. This has been shown to occur in deep water running with the result that novice subjects demonstrate high HR for a given $\dot{V}O_2$ whereas skilled subjects show similar HR-VO_2 relationships to land. Furthermore, the line is shifted to the right after a period of deep water run training (Michaud et al.,1995). Thus, physically deconditioned patients with RA may rely on type II fibre activation at a slower speed than normal subjects and training may alter the HR-$\dot{V}O_2$ relationship as muscle strength increases and the aerobic pathways are stimulated.

Preferential type II fibre activation is also suggested by the greater percentage increases in $\dot{V}_E$ relative to $\dot{V}O_2$ in water compared to land. As subjects were utilising approximately 60% of $\dot{V}O_{2\,\max}$ at 4.5 km·h^{-1} with a RPE of 14 it is possible that the ventilatory threshold had been reached. Furthermore, the RER was 0.95 suggesting that more carbohydrate than fat was metabolised. The shift from fat to carbohydrate metabolism occurs, in part, due to the recruitment of fast muscle fibres which are activated in response to the increasing resistance as speed increases in water. In chapter 5 similar $\dot{V}_E$ - $\dot{V}O_2$ relationships in normal female subjects who walked on land and water treadmills at 4.5 km·h^{-1} were reported. However, deconditioned patients may rely on type II fibre activation at slower speeds than normal subjects. Appropriate training will enhance aerobic pathways, but given that preferential type II activation is associated with earlier onset of fatigue, a longer training programme may be required before beneficial changes become apparent. Alternatively a muscle strengthening programme prior to or alongside the aerobic conditioning may enhance patients ability to maintain higher speeds in water. Whilst the data are suggestive of anaerobiosis further research in which the speed scale is extended is required to examine the linearity of response.

The HR-$\dot{V}O_2$ relationship in this study has important implications for exercise prescription and monitoring. Land based HR values offer a convenient means of quantifying exercise intensity. If used to monitor water based walking exercise in RA patients it would overestimate the metabolic demand. For example, a land based HR of 107 beats·min^{-1} corresponds to a $\dot{V}O_2$ of 0.74 l·min^{-1} on land but only 0.6 l·min^{-1} in water. To achieve a similar land based $\dot{V}O_2$ a HR of 116 beats·min^{-1} would be required. Therefore, to equalise oxygen uptake on land and water treadmills, RA patients would need to increase HR by approximately 9 beats·min^{-1}.

The metabolic demands of walking in chest-deep thermoneutral water altered depending on speed. At 2.5 km·h^{-1} $\dot{V}O_2$ and HR were lower in water than on land. Lower levels of $\dot{V}O_2$ suggest that resistance to movement is minimal and buoyancy effects dominate causing a lower metabolic demand than on land. Muscle activity during slow movement is less in water than on land and this may account for both the lower HR and $\dot{V}O_2$ at 2.5 km·h^{-1} (Kelly et al., 2000). Furthermore, the exercise intensity at 2.5 km·h^{-1} was low and so the lower HR may be a consequence of the cephalad redistribution of blood during head-out water immersion which increases stroke volume with slight decrements in HR (Yamazaki et al., 2000). At 3.5 km·h^{-1} $\dot{V}O_2$ was lower in water and HR similar to land walking suggesting that the effects of exercise were beginning to supercede the effects of head-out water immersion. A lower $\dot{V}O_2$ at this speed differs from the results in Chapter 5 which showed similar $\dot{V}O_2$ values and previous reports which showed higher values (Gleim and Nicholas, 1989) during water treadmill walking. The differences between studies may reflect variations in water depth and subject characteristics. The effects of buoyancy on percentage weight bearing in women have shown that immersion to the xiphoid process unloads the lower limbs by 72%, resulting in only one-third of the body weight being transmitted to the ground (Harrison and Bulstrode, 1987). Immersion to the anterior superior iliac spines produced a percentage weight bearing of 47%. Therefore, it is plausible that differences between waist, as reported by Gleim and Nicholas (1989) and chest immersion could alter the metabolic demand of exercise in water because buoyancy supports the body weight and reduces postural muscle activity (Sugajimo et al., 1996). At 4.5 km·h^{-1} $\dot{V}O_2$ in water was similar to land and HR higher. Higher $\dot{V}O_2$ was reported in Chapter 5, confirming Gleim and Nicholas' work (1989) and suggests that the effects of buoyancy are superceded by the greater resistance to movement as speed increases. However, the similar $\dot{V}O_2$ between water and land treadmill walking presented here implies that the effects of buoyancy while less than at slower speeds, was still evident. This may relate to differences in body composition between normal subjects and RA patients who, by virtue of muscle atrophy and bone loss, have a reduced lean body mass which would result in greater buoyancy in water (Hakkinen et al., 1999a; Rall and Roubenoff, 1996)

In water, at rest, systolic blood pressure was similar to land but diastolic was lower by approximately 10mmHg. These findings differ from those in Chapter 3 but there is considerable controversy over blood pressure responses during head-out water immersion with Epstein (1992) concluding that thermoneutral immersion does not affect BP whilst others have reported falls in diastolic BP (Sramek et al., 2000; Weston et al., 1987). A lack of unanimity may reflect differences in arm and body posture, water depth and temperature, equipment and subject characteristics (eg, age) between studies. Similar increases in systolic blood pressure after land and water exercise were observed. These results differ from those in Chapter 5 but corroborate with data from other water exercise studies, albeit cycle ergometry (Hanna et al., 1993; Sheldahl et al., 1992 and 1987; Christie et al, 1990; Connelly et al., 1990). This suggests that the cardiovascular adjustments during dynamic exercise were not changed by water immersion, despite the assumed increase in $\dot{Q}$. However, further research is required to clarify the BP responses during water treadmill walking in different age groups of various health status.

Insight into the altered biomechanical demands of water exercise may be gained from the differences in stride frequency and the altered perception of effort observed during water and land treadmill walking. The resistance of the water makes it difficult to generate the limb speeds observed on land and therefore stride frequency was significantly lower in water than on land at all speeds. This was observed in Chapter 3 and is generally reported as being 30% lower in water (Hall et al., 1998; Frangolias and Rhodes, 1996; Yu et al., 1994; Town and Bradley, 1991; Evans et al., 1978). A lower cadence implies longer contraction times which may result in rhythmic ischaemia with consequent reduced oxygen delivery and greater reliance on anaerobic pathways.

At 3.5 and 4.5 km·h^{-1} RPE-legs was higher in water than on land but RPE-breathing was similar between conditions and speeds. This suggests that the limiting factor was local fatigue rather than cardiovascular and ties in with the theory of enhanced type II fibre activation in water. For a given $\dot{V}O_2$ or HR, RPE was higher in water than on land by approximately 1-2 points. Therefore, exercise intensity based on land-derived RPE-legs values would overestimate the metabolic demand in water. The disparity between perceived effort and physiological cost has been reported in other studies (Bryne et al., 1996; Glass et al., Yu et al., 1994; 1995; Svedenhag and Seger, 1992). The reasons for greater perceived exertion in water may rest on the altered muscle activation patterns as a result of the resistance to movement.

As a consequence of the warmth of the water and the buoyancy mediated reduction in joint loading it was hypothesised that pain would be less and knee range of movement greater following the water test compared to land walking. However, no differences in pain scores were observed between water and land walking. This may reflect the low baseline scores, the lack of sensitivity of a global measure, or the lack of a carry-over effect from water to land. Given the close association between pain and joint tenderness that was observed in Chapter 2 and the finding that patients receiving hydrotherapy had a 27% reduction in the Ritchie Index after treatment it would have been interesting to examine joint tenderness before and after the walking tests and to include joint specific measures of pain (Hall et al., 1996). Despite the properties of the water knee range of movement did not alter after the walking test. However baseline values showed normal ranges of movement and the lack change most likely reflects a ceiling effect.

This study supports the hypothesis that the intensity of exercise during water treadmill walking at 4.5 km·h^{-1} was sufficient to stimulate a cardiorespiratory response high enough to induce an aerobic training effect in patients with RA. Given the low $\dot{V}O_{2\,max}$ (1.24 to 1.47 l·min^{-1}) reported for women with RA (Ekdahl and Broman, 1992) and applying this to the present study suggests that patients were walking at approximately 55-65% of their $\dot{V}O_{2\,max}$ at 4.5 km·h^{-1} in water. Heart rate ranged from 55-75% of the predicted maximal heart rate (PMHR) over the walking test and RPE scored 14 at 4.5 km·h^{-1}. Therefore, it is clear that walking at the fast speed provided a cardiorespiratory stimulus, in line with ACSM recommendations for aerobic conditioning (40-85% $\dot{V}O_{2\,max}$, 55-90% HR_{max}, 12-16 on the 15-point RPE scale)(1991). However, even at 3.5 km·h^{-1} $\dot{V}O_2$ and HR were approximately 40% and 63% of $\dot{V}O_{2\,max}$ and HR_{max} respectively and RPE-legs scores were close to the lower training target of 12. Therefore, for some patients, especially those with the lowest aerobic endurance, walking at 3.5 km·h^{-1} was likely to provide a cardiorespiratory stimulus. The use of previous data from land based studies for estimating $\dot{V}O_{2\,max}$ introduces error into the calculations that future studies could address by including a maximal exercise test.

6.6. CONCLUSIONS

A continuous and incremental walking test in water and on land in patients with RA showed that the HR-$\dot{V}O_2$ relationship was shifted to the left, such that HR was higher for a given VO_2. This may be a result of thermal loading in a deconditioned sample and unfamiliar biomechanical demands. In clinical terms prescribing and monitoring exercise intensity in hydrotherapy pools for patients with RA based on land-derived values of HR will overestimate exercise intensity. Therefore land based HR should be increased by 9 beats$\cdot$min^{-1} when exercising in water.

This study has demonstrated that walking at 4.5, and possibly 3.5 km$\cdot$h^{-1} , in chest deep thermoneutral water provides a cardiorespiratory stimulus in patients with RA. Therefore, walking in water at speeds between 3.5 and 4.5 km$\cdot$h^{-1}, for the recommended duration of 15-60 minutes (continuous or discontinuous) 3-5 times a week should result in greater aerobic endurance and hence lower levels of fatigue (ACSM, 1991). It was outwith the scope of this study to investigate the ability of patients to walk for the minimum duration of 15 minutes at 4.5 km$\cdot$h^{-1}. Anecdotal evidence, based on patients' perceptions, suggests that some patients would have fatigued before the minimum time period. Therefore, interval training or a lower limb muscle strengthening programme prior to the aerobic challenge may be the most appropriate method to improve aerobic capacity in RA patients.

CHAPTER 7

DISCUSSION AND CONCLUSIONS

7.1. INTRODUCTION

Hydrotherapy is a popular choice of treatment, being appreciated by RA patients for its pain relieving and movement enhancing qualities and employed by physiotherapists for its potential to simultaneously increase range of movement and muscle strength with pain reduction. The evidence base for hydrotherapy has been indirect and current practice relies on inferences from immersion studies and the effects of temperature on the body (Hall et al., 1990). The aims of this thesis have been to investigate the efficacy of hydrotherapy and its utility for increasing aerobic endurance in patients with RA so that recommendations regarding exercise prescription in water can be made.

Studies on the efficacy of hydrotherapy have been scarce and none have compared the therapeutic possibilities of immersion. Immersion *per se* dominated the use of water as a healing agent in the past and there have been recent advances in knowledge of the physiological effects of head-out water immersion. It is therefore surprising that the work presented here represents the first attempt to investigate the physiotherapeutic benefit of relaxation in warm water. However, understanding of the benefits of exercise, particularly in deconditioned patients such as RA, make the argument that the combination of exercise and immersion is superior to either of these components on their own. The work presented in Chapter 4 supports this hypothesis and provokes the question "could the benefits result from an improvement in aerobic capacity given patients' anecdotal reports that moving in water was easier than on land?". Whilst a prospective design could have been used to test this hypothesis it was considered prudent to examine the potential of hydrotherapy to stimulate cardiovascular improvements. An underwater treadmill, not previously used in this country, provided an excellent research tool, allowing the development of a functional walking test. Because the cardiorespiratory responses to water treadmill walking had not been fully characterized, a study in which normal females performed an incremental exercise test was completed before the model was applied to patients with RA. These studies demonstrated that both normal subjects and patients with RA could walk at a speed commensurate with a cardiorespiratory stimulus with patients reaching their target HR at lower speeds. The interaction between buoyancy and viscosity was shown to have a significant effect on energy expenditure. Buoyancy dominated in slow walking resulting in minimal cardiorespiratory stress whilst fast walking elicited higher or similar $\dot{V}O_2$ values to land treadmill walking. The HR-$\dot{V}O_2$ relationship in water differed from that on land, making land-based exercise prescription unreliable for exercise in water. In cold water, HR was lower in water than on land for a given $\dot{V}O_2$ in normal subjects and patients with RA demonstrated higher HR when in thermoneutral water. Therefore, exercising in water, at the temperatures reported, on the basis of land derived HR values would overestimate metabolic demand in the case of normal subjects and underestimate it in patients with RA. Consequently, on the basis of present evidence, patients with RA exercising in thermoneutral water should increase their land based HR by 9 beats$\cdot$min^{-1} to achieve a comparable metabolic demand. Whilst Chapters 3 and 4 showed that a cardiorespiratory training stimulus was feasible a prospective study is required to test the hypothesis that exercise in water results in enhanced aerobic capacity in patients with RA. Given that Schultz et al. (1995) calculated overestimates of effectiveness in dependent variables in non-randomised clinical studies to be approximately 40% a randomised clinical trial would be the preferable study design for such a trial. However, randomised clinical trials are time consuming and expensive to conduct and so it would be prudent to confirm the HR-$\dot{V}O_2$ relationship and examine other variables as a basis for exercise prescription in a larger sample of heterogenous RA patients.

7.2 ARE THE THERAPEUTIC BENEFITS OF HYDROTHERAPY MEDIATED BY AN INCREASE IN AEROBIC CAPACITY ?

The findings from the treadmill study on RA patients showed that an aerobic stimulus was possible when walking at moderately fast speeds in water. It is plausible to suggest, given that patients in the treadmill study may be viewed as a sub-group of the hydrotherapy sample, that minor increases in aerobic capacity may have mediated therapeutic benefit in the hydrotherapy study. However, the external validity of these results may be limited because of the homogenous sample tested. Whilst the treadmill patients had a similar age range to half of those in the hydrotherapy study only a third of the hydrotherapy patients had a disease duration of less than 5 years. On average, the treadmill patients were younger (47 $\pm$ 8.05 versus 55.8 $\pm$ 12.8 years), had a shorter disease duration (3.1 $\pm$ 1.3 versus 9.7 $\pm$ 7.7 years) and lower Ritchie score (11.4 $\pm$ 9.5 versus 21.3 $\pm$ 10.6) than the patients undergoing the hydrotherapy intervention. This implies less deconditioning in the treadmill study patients than those undergoing the hydrotherapy intervention. Whether older patients of longer disease duration would demonstrate similar cardiorespiratory responses could not be ascertained from the present data. However, given their relatively greater level of deconditioning it might be surmised that the HR-$\dot{V}O_2$ curve would be further shifted to the left, caused by a higher HR for a given metabolic demand. It is possible that these patients could reach their target HR values without achieving an aerobic conditioning stimulus. Such a scenario would limit exercise duration, not only for safety reasons, but because the exercise is fueled primarily through anaerobic metabolism. The pilot study, prior to the treadmill study, showed that patients with RA were unable to walk as fast as normal subjects. It is therefore unlikely that older RA patients with longer disease duration and relatively greater muscle weakness would be able to walk at the speeds adopted in the treadmill study on RA patients. Walking at 3.5 $km{\cdot}h^{-1}$ on the water treadmill yielded the minimum energy expenditure to provoke a cardiorespiratory training effect as recommended by the ACSM. As slow walking speeds were shown to elicit minimal energy expenditure patients unable to walk at 3.5 $km{\cdot}h^{-1}$ may not experience an aerobic stimulus. Alternatively, the compromise between slow movement and buoyancy, versus fast movement and resistance, on metabolic demand in weak patients may reduce the speed threshold. Given these arguments it would appear unlikely that the therapeutic benefits of hydrotherapy, as reported in Chapter 4 were mediated by enhanced aerobic endurance. Further research on the cardiorespiratory responses is required to establish the metabolic pathways utilised by older RA patients of long-standing disease duration and to examine metabolic changes following a period of training. The speed of walking in both normal subjects and RA patients completing the treadmill studies was limited by muscle strength (as evidenced by higher RPE-legs rather than RPE-breathing scores) therefore a muscle strengthening regime prior to aerobic conditioning may enable very deconditioned patients to reach threshold speeds.

7.3. HEART RATE – OXYGEN CONSUMPTION RELATIONSHIPS

The relationship between HR and $\dot{V}O_2$ varied for each of the two conditions under which it was studied, that is, water temperature and conditioning status of the sample. In water at 28°C HR was lower than seen on land, for a given $\dot{V}O_2$ and this represents a thermoregulatory response. In water at 35.8°C the HR-$\dot{V}O_2$ relationship was similar to land. This was contrary to the hypothesis that anticipated a higher HR for given $\dot{V}O_2$ but the relatively short test duration and the low exercise intensity (approximately 40% $\dot{V}O_{2\,max}$) probably negated a thermoregulatory influence. Patients with RA demonstrated a higher HR for a specified $\dot{V}O_2$. Given that the water temperature of 34.5°C was approximately thermoneutral for exercise in water, and sublingual temperature increased by 0.37°C only it is unlikely that thermoregulatory demands affected the relationship. RA patients were older (47 ± 8.05 years) than the normal subjects (30.25 ± 6.3 years) and so the differences between the HR-$\dot{V}O_2$ curves may suggest age-dependent effects. However, studies directly comparing the HR-$\dot{V}O_2$ relationship in young and old healthy subjects during shallow water running (Takeshima et al., 1997) and deep water running (Brown et al., 1998) refute this. The major difference between treadmill study groups was the conditioning status of the subjects. RA patients had a higher resting HR (71 ± 8.6 versus 68 ± 6.4 beats·min^{-1}) and lower ADFS scores (median : 1 versus 3) than the normal subjects. The HR-$\dot{V}O_2$ curve elicited in RA patients is similar to that seen in cross-sectional studies of conditioned versus deconditioned subjects and supports the hypothesis that the results presented here reflect deconditioning. This means that cellular respiration cannot be met by an adequate O_2 supply and glycolytic pathways are predominantly fuelling the muscle contraction, resulting in lactate accumulation and chemoreceptor mediated increases in HR. Glycolytic pathways are preferentially utilized when type II muscle fibres are recruited. Given their reduced muscle strength RA patients are likely to have recruited a greater percentage of Type II fibres than normals to overcome a given resistance or speed in water. The finding that RA patients had higher RPE-legs scores for a given speed than normal subjects supports this argument. Furthermore, for a 1 $km{\cdot}h^{-1}$ speed increase, the percentage increase in $\dot{V}O_2$ was higher in normal subjects than RA patients (52.5% versus 42%) suggesting greater utilization of O_2 in normal subjects. As RPE is reflective of metabolic cost high scores equate to greater energy expenditure with greater anaerobic contribution to ATP production. Preferential utilization of glycolytic pathways in the completion of a specific task results in earlier fatigue and therefore patients with RA may be unable to complete an aerobic training session in the traditional 20-minute fashion because of lactate accumulation. Physiotherapists need to be aware of this and consider altering short bursts (5 minute) of aerobic conditioning with less demanding work, ie, interval training.

Comparisons between expert and novice subjects undergoing deep water running in thermoneutral water show similar HR-$\dot{V}O_2$ relationships to that seen in the RA treadmill study and support the deconditioning theory (Yamaji et al., 1990). Furthermore, in novice subjects the curve shifts to the right after 8 weeks of training (Michaud et al., 1995a). Land training results in cardiorespiratory gains of a similar magnitude in RA patients and sedentary controls (van den Ende et al., 1998) and therefore it would be expected that water training would be equally effective. Whether similar gains would be achieved within the same timescale given that RA patients fatigue faster than age and sex-matched controls would need to be examined.

If training shifts the HR-$\dot{V}O_2$ relationship to the right this has implications for exercise prescription and highlights the urgency of further research on training responses in deconditioned patients.

7.4. EXERCISE PRESCRIPTION

The incorporation of an effective aerobic component into hydrotherapy programmes demands methods of accurate exercise prescription. Where this has been considered HR or RPE have been used as an indicator of aerobic exercise intensity because of the linear relationships between these variables on land. However the results of this thesis show that these relationships are affected by water temperature and conditioning status during chest-deep water treadmill walking. Therefore using land-based HR or RPE values to estimate exercise intensity is inaccurate. In the case of patients with RA, land-based HR values would underestimate exercise intensity in water. In Chapter 6 it was recommended that clinicians increase land-based HR by 9 beats·min^{-1} to ensure a comparable metabolic load in water. Whilst this represents the best available evidence to date it should be noted that confirmation of these results is required, given that this study used relatively few patients and was limited to 3 data points. Furthermore, if, as is argued in the previous section, the altered HR-$\dot{V}O_2$ relationship is the result of deconditioning, then clinicians need to be aware that the exercise prescription may change over the course of conditioning programme as the patients becomes "fitter". The literature suggests that the HR-$\dot{V}O_2$ curve shifts towards that of land following 8 weeks of aerobic conditioning in water in normal subjects (Michaud et al., 1995a). Therefore, within the limits of the data reported here, and assuming the literature is relevant for patients with RA, it is possible to advise clinicians to begin a conditioning programme in water with a 9 beats·min^{-1} higher HR than predicted on land, and after 8 weeks reduce it to land-based values. However, this approach may be as imprecise as present methods and reiterates the need for better methods of exercise prescription in water, as well as a prospective study of aerobic training in water.

The use of HR as an indicator of exercise intensity is fraught with difficulty as the literature attests. Because of the large number of variables involved in determining the relationship, Cureton (1997) cautions against this method of exercise prescription. He lists, exercise intensity (speed of movement in water), exercise mode, muscle mass activated and water temperature and depth as the important factors. Furthermore, this thesis suggests that conditioning status of the patients is also a determining variable.

Exercise intensity is also prescribed from the relationship between RPE and $\dot{V}O_2$ during land-based activity and applying this formula to water exercise depends on a similar relationship in water. However, this thesis demonstrates that this relationship is altered depending on the fitness of the subject. Normal subjects exhibited similar relationships on land and water but RA patients showed significantly higher RPE-legs for a given $\dot{V}O_2$ in water. Therefore, utilising land-based RPE values to prescribe exercise intensity in water would overestimate metabolic demand. To suggest that clinicians should prescribe exercise in water on the basis of higher RPE scores may be as premature as altering the HR given the unknown effects of a water conditioning programme on the RPE-$\dot{V}O_2$ relationship. However, with this knowledge it may be recommended that clinicians begin the water programme by prescribing a higher RPE (by 1-2 point on the 6-20 RPE scale) than that on land.

Clearly neither HR nor RPE appear accurate indicators of exercise intensity in water but given the large number of variables associated with the HR response further study of the RPE-$\dot{V}O_2$ relationship is warranted. The problem of accurate exercise prescription has dogged deep water running research, although Wilder et al. (1993), have proposed that cadence could provide a more accurate estimate than either HR or RPE. However neither HR nor $\dot{V}O_2$ correlated highly or significantly in either of the treadmill studies suggesting that cadence would not be a suitable environment-specific measure of exercise intensity during water treadmill walking.

Given the differences in frontal resistance between shallow water walking and water treadmill walking it cannot be certain that similar HR-$\dot{V}O_2$ or RPE-$\dot{V}O_2$ relationships will be observed. Two studies in normal young subjects have reported that the HR-$\dot{V}O_2$ relationship during shallow water walking is linear and comparable to land treadmill work, implying that metabolic intensity may be accurately prescribed from land-based treadmill HR (Yu et al., 1994; Evans et al., 1978). However, using RPE to prescribe water exercise may underestimate intensity because Yu et al. (1994), reported higher RPE for a given $\dot{V}O_2$. Whether these results remain pertinent for a patient with RA in thermoneutral pools is unknown and requires further research efforts. Two studies, which will enable the development of accurate exercise prescription methods for patients with RA in water, are recommended. Firstly, a water treadmill study with a sample displaying similar age and disease duration characteristics as those in the randomised clinical trial and incorporating multiple data point collection and secondly, comparison of shallow water walking to water treadmill walking. The 2 studies share a common aim, namely to examine cardiorespiratory and perception of effort relationships during walking in water. Therefore the same patients could perform both water tests (ie, water treadmill and shallow water walking) as well as a land treadmill test for comparison purposes. Exercise intensity would be matched for $\dot{V}O_2$ given that HR, RPE and cadence are likely to differ in the different environments and incremental stages of 0.5 km·h^{-1}, starting at this speed would be examined until the patient was unable to perform the correct walking technique or wished to stop. Such a test is likely to incur near maximal responses and so appropriate safety measures, including ECG monitoring, would need to be instituted (ACSM), especially as Komatireddy et al. (1997), reported that 4% of his sample demonstrated cardiopulmonary abnormality during a modified Bruce protocol. Given the recommended length of each incremental stage (5 minutes) the exercise tests could be discontinuous so that patients were able to rest for a specified interval (Takeshima et al., 1997) and as well as measures of $\dot{V}O_2$, HR, RPE and S_f blood lactate would provide additional information concerning the metabolic pathways utilised.

Whilst it is recognised that further work is required on developing accurate exercise prescription methods in water for patients with RA the best available evidence recommends that target HR or RPE, based on land norms be increased by 9 beats·min^{-1} or 1-2 on the RPE scale respectively.

7.5. PROPOSED RANDOMISED CLINICAL TRIAL

A randomised clinical trial to test the hypothesis that an aerobic conditioning programme in water for patients with RA results in improvement in aerobic capacity would require individualised and accurate exercise prescriptions for those in the experimental group. Presently the most accurate exercise prescriptions are based on a percentage of $\dot{V}O_{2\,max}$ identified during a maximal exercise test on a land treadmill or cycle ergometer. Exercise is performed at a target HR or RPE which equates to the desired percentage of $\dot{V}O_{2\,max}$, which for aerobic training purposes is 40-85% of $\dot{V}O_{2\,max}$ (ACSM). Using these data to prescribe exercise in water for patients with RA, will, as has been seen, be inaccurate. Therefore, on the evidence to date, the HR target for patients with RA, exercising in thermoneutral water, should be increased by 9 beats·min^{-1}, or the RPE should be increased by 1-2 points on the 6-20 scale. However, these data requires validation prior to initiating a randomised clinical trial. Patients in the control group would experience similar duration and frequency of treatment but not be exposed to exercise of an intensity likely to improve aerobic capacity. They would, therefore perform simple range of movement exercises using slow movements enhanced by buoyancy. The primary endpoints would be improved aerobic capacity, pain and quality of life as recommended by Verhagen et al. (2000) and Molenaar et al. (2000). Secondary measures would include the disease activity score, activity and fatigue levels and measures of self-efficacy (van Riel et al., 2000; van der Heijde et al., 1993; Lorig et al., 1989). A response criteria of 15% would be set for aerobic capacity increases given the anticipated increases in $\dot{V}O_{2\,max}$ following a 12 week aerobic programme (Takeshima et al., 2002; Powers and Howley, 2001). An initial estimate of sample size, based on a 15% (±5%) improvement suggests that 144 patients would be required (16 x $(\triangle/SD)^2$. Patients, meeting the entry criteria described in Chapter 2, would be randomised to either aerobic or non-aerobic groups following successful completion of a symptom limited incremental treadmill test on land. All patients would complete the outcome assessments before and after the intervention and again at 3-month follow-up. Patients would attend the hospital hydrotherapy pool 3 times weekly for 45 minutes for a period of 12 weeks. As cardiorespiratory endurance is defined as the ability to perform dynamic, moderate to high-intensity work using a large muscle mass for an extended period of time the exercises incorporated into the hydrotherapy programme would consists of walking and dancing type activities (Wannamethee and Sharper, 2001). Following a warm-up, four 5 minute bouts of aerobic exercise at the target intensity would be interspersed with 5 minute bouts of non-aerobic activity (resistance training for major upper and lower limb muscle groups). If target HR was selected as the measure of exercise intensity continuous monitoring, using a Polar HR device, would be instituted during each hydrotherapy session to ensure that the training intensity was maintained as prescribed. If target RPE was selected as the measure of exercise intensity patients would be reminded of the importance of reaching the target at each aerobic session. A second exercise test would be performed after 6 weeks of hydrotherapy so that the exercise prescription could be adjusted for the aerobic group if required. Regression analysis could be used to identify the characteristics of patients who perform best (using pre-set criteria) as this information will help physiotherapists to select the most appropriate patients for hydrotherapy.

7.6. RECOMMENDATIONS AND FUTURE DIRECTIONS

The randomised clinical trial, presented in Chapter 4, demonstrated that the combination of exercise and immersion, as in hydrotherapy, provided superior therapeutic benefit than its components. On the basis of these results immersion per se should not be recommended as a treatment option but relaxation periods within a hydrotherapy programme are important to allow recovery. Relaxation on land, in the form of Jacobsen's progressive relaxation (Jacobsen, 1938) elicited significantly more pain and this may have been related to the isometric contractions required prior to relaxation. Therefore, this method of relaxation cannot be recommended for patients with RA and alternative forms may be of more benefit (Huntley et al., 2002).

Dynamic exercise for patients with RA is considered to elicit positive health related benefits, which have been confirmed despite the short-term nature of the intervention in the studies reported in this thesis. Hydrotherapy may be recommended for patients with RA because of its additional benefits. However, the mechanisms underlying the improvements, the exact parameters that define the exercise and type of RA patient that benefits the most requires further research. On the basis of the research presented here patients with RA should be encouraged to engage in hydrotherapy but given the lack of such services land exercise must be continued. The lack of suitable hydrotherapy facilities needs to be addressed by a multidisciplinary body consisting of hospital-based personnel, patients' bodies and the recreation and leisure industry so that a seamless progression of water exercise availability is presented to patients at diagnosis. Whilst such an initiative has already proved successful the content of hydrotherapy programmes, the long-term adherence and the patients most likely to benefit require further consideration (Reilly and Bird, 2001).

Whilst the mechanisms underlying the health related benefits associated with hydrotherapy are likely to be multifactorial this thesis examined the possibility of an increase in aerobic capacity. One of the major benefits claimed for hydrotherapy is its ability to improve cardiorespiratory endurance in a gravity-reduced environment and this is important for patients with RA who are deconditioned. It was demonstrated that water treadmill walking above a speed threshold could stimulate an aerobic response in RA patients and that energy expenditure in water was affected by the speed of walking. Therefore, given a suitable speed selection, it is possible that water treadmill walking could be used as a cardiorespiratory conditioning device for RA patients. Further research is required to test the hypothesis that chronic adaptation to aerobic training occurs after a period of water treadmill training in RA patients. This requires accurate methods of exercise prescription in water. From the present data, patients with RA should add 9 beats$\cdot$min^{-1} or 1-2 points on the 6-20 RPE scale to their land-based exercise prescription to achieve a similar metabolic demand. Whilst this represents the best available evidence the study limitations are acknowledged and further research, as outlined earlier, is required. Physiotherapists should be aware that small increments in speed result in larger increases in energy expenditure in RA patients compared to normal subjects and therefore should increase speed judiciously. Furthermore, the duration of aerobic training may need to be altered for patients with RA because of their reduced muscle strength and the fact that increasing speed in water may preferentially activate Type II muscle fibres and anaerobic pathways. Therefore, the aerobic component could be divided into several short burst (eg, 5 minute) interspersed with less vigorous activity. For this reason, the temperature of pool facilities should be maintained at 34.5°C. Some patients may be unable to move fast enough in water to stimulate an aerobic effect because of muscle weakness and therefore prior muscle strengthening may provide the key to later improvements in cardiorespiratory function but this needs to be investigated in future studies. Similarly, the cardiorespiratory responses of walking on a water treadmill need to be examined alongside those of shallow water, which, in the UK at present, is more available to patients with RA.

The results of this thesis suggest that 2 studies are required in hydrotherapy, both of which have been detailed earlier. First, confirmation and further examination of reliable methods of prescribing exercise intensity in water are required. Secondly, a randomised clinical trial to test the efficacy of improving aerobic capacity during hydrotherapy, which utilises the results from the previous study, will identify the patient characteristics associated with best effect. In this way hydrotherapy could be targeted at a more specific population in a more specific format. Issues of cost-effectiveness, mechanisms of action, service delivery and long-term adherence also need to be addressed within the wider context of hydrotherapy.

7.7. CONCLUSIONS

Dynamic exercise for patients with RA, has only been used relatively recently, and, has assumed great importance in their long-term management because research has proven it to be safe and effective in promoting health-related benefits. Aerobic exercise is considered vital in preventing and reversing the physical deconditioning associated with RA. Hydrotherapy provides an ideal environment for exercise because of the warmth and buoyancy of the water and the evidence-base for its efficacy has been strengthened by the randomised clinical trial presented in this thesis. In a recent systematic review of balneotherapy it scored highly for methodological quality (Verhagen et al., 2000). It has been assumed that hydrotherapy can increase cardiorespiratory fitness and whilst this has been shown in some studies the methodological rigour was unsatisfactory and methods of accurate exercise prescription lacking. The mechanisms underlying the efficacy of hydrotherapy may include an increase in aerobic capacity but the balance between buoyancy and viscosity alters the energy demands in water and may result in a high HR for a low metabolic demand. Because of the log increase in resistance to speed in water muscle strength is the dependent factor to moving fast enough to stimulate the cardiorespiratory system. Therefore, patients with RA who have poor muscle strength may be unable to move at a speed in water commensurate with aerobic conditioning. This anomaly has been highlighted in the previous chapters together with examination of methods of exercise prescription and monitoring of exercise intensity in water. Further research to develop the most accurate method of exercise prescription in water is required followed by a randomised clinical trial to examine the efficacy to improve aerobic capacity in RA patients. Despite the limitations of the studies presented here the evidence suggests that hydrotherapy provides health-related benefits to functionally independent patients with RA and therefore greater provision needs to be made now, especially in non-hospital environments which will aid in the de-medicalisation of treatment and may enhance long-term adherence to exercise.

REFERENCES

*** reprints may be found at the back of the thesis.**

Ahern M, Nicholls E, Simionato E, Clark M and Bond M. (1995). Clinical and psychological effects of hydrotherapy in rheumatic diseases. *Clinical Rehabilitation.*, 9, 204-212.

Allied Dunbar National Fitness Survey. (19920. The Sports Council and the Health Education Authority. London. SC/82/100M/6/92.

Alexander GJM, Hortas C and Bacon PA. (1983). Bed rest, activity and the inflammation of rheumatoid arthritis. *British Journal of Rheumatology.*, 22, 134-140.

Altman DG. (1991). *Practical Statistics for Medical Research*, pp. 455-457. London : Chapman and Hall.

American College of Sports Medicine. (1991). *Guidelines for Exercise Testing and Prescription.* Malvern PA : Lea and Febiger.

Anderson JJ, Firschein HE and Meenan RF. (1989). Sensitivity of a health status measure to short-term clinical changes in arthritis. *Arthritis and Rheumatism.*, 32, 844-850.

Arborelius M, Balldin U, Lilja B and Lungren C.(1972). Haemodynamic changes in man during immersion with the head above the water. *Aerospace Medicine.*, 43, 592-598.

Arnett FC, Edworthy SM, Bloch DA, et al (1988). The American Rheumatism Association 1987 revised criteria for the classification of rheumatoid arthritis. *Arthritis and Rheumatism.*, 31, 315-324.

Astrand P-O and Rodahl K. (1986). *Textbook of Work Physiology.* New York : McGraw-Hill Book Co.

Badley EM, Wagstaff S, Wood PHN. (1984). Measures of functional ability (disability) in arthritis in relation to impairment of range of joint movement. *Annals of Rheumatic Diseases.*, 43, 563-569.

Balldin UI, Lundgren CEG, Lundvall J and Mellander S. (1971). Changes in the elimination of 133 Xenon from the anterior tibial muscle in man induced by immersion in water and by shifts in body position. *Aerospace Medicine.,* 42, 489-493.

Balogun JA, Akomolafe CT and Amusa LO. (1991). Grip strength:effects of testing posture and elbow position. *Arch Phys Med Rehabil.*, 72, 280-283.

Bates A and Hanson N. (1996). A*quatic Exercise Therapy.* London : WB Saunders

Ltd..

Beals CA, Lampman RM, Banwell BF, Braunstein EM, Albers JW, Castor CW. (1985). Measurement of exercise tolerance in patients with rheumatoid arthritis. *Journal of Rheumatology.*, 12, 458-461.

Beattie P. (2001). Measurement of health outcomes in the clinical setting : applications to physiotherapy. *Physiotherapy Theory and Practice.*, 17, 173-185.

Becker BE. (1997). Aquatic physics. In : Ruoti RG, Morris DM and Cole AJ (eds) *Aquatic Rehabilitation,* pp. 15-23. New York : Lippincott.

Bellamy N, Sothern RB, Campbell J, Buchanan WW. (1991). Circadian rhythm in pain, stiffness, and manual dexterity in rheumatoid arthritis : relation between discomfort and disability. *Annals of Rheumatic Diseases.*, 50, 243-248.

Bird HA and Wright V. (1982). Assessments in the rheumatic diseases. In : Bird HA and Wright V, eds. *Applied Drug Therapy of the Rheumatic Diseases,* pp. 40-61. Bristol : Wright PSG.

Bisson Dl, Dunster GD, O'Hare JP, Hampton D and Penney MD. (1992). Renal sodium retention does not occur during the luteal phase of the menstrual cycle in normal women. *British Journal of Obstetrics and Gynaecology.*, 99, 247-252.

Blake DR, Merry P, Unsworth J, Outhwaite J, Morris CJ, Gray L, Lunec J. (1989). Hypoxic-reperfusion injury in the inflamed human joint. *Lancet.*, I, 289-293.

Blyden G, Silverstein F, Epstein M, Norsk P, Brenner B, Nwadike N and Dorvil M. (1989). Lidocaine pharmacokinetics during water immersion in normal humans. *Journal of Applied Physiology.*, 66, 57-60.

Bohannon RW. (1987). The clinical measurement of strength. *Clinical Rehabilitation.*, 1, 5-16.

Bohannon RW. (1986). Test-retest reliability of hand-held dynamometry during a single session of strength assessment. *Physical Therapy.*, 66, 206-209.

Bombardier C, Tugwell P, Sinclair A, Dok C, Anderson G and Buchanon WW. (1982). Preference for endpoint measures in clinical trials : the results of structured workshops. *The Journal of Rheumatology.*, 9, 798-801.

Borg GAV. (1982). Psychophysical basis of perceived exertion. *Medicine and Science in Sports and Exercise .*, 14, 377-381.

Boström K, Harms-Ringdahl K, Nordemar R. (1995). Relationships between measurements of impairment, disability, pain and disease activity in rheumatoid arthritis patients with shoulder problems. *Scand J Rheumatol.*, 24, 352-359.

Boström K, Harms-Ringdahl K, Nordemar R. (1991). Clinical reliability of shoulder function assessment in patients with rheumatoid arthritis. *Scand J Rheumatol.*, 20, 36-48.

Bowers KS. (1968). Pain, anxiety and perceived control. *Journal of Consulting and Clinical Psychology.*, 32, 596-602.

Bowling A. (1999). Social research on health : sociological and psychological concepts and approaches. In : Bowling A, ed. *Research methods in health.* P36. Buckingham : Open University Press.

Brechat P-H, Wolf J-P, Simon-Rigaud M-L, Brechat N, Kantelip J-P, Bertherlay S and Regnard J. (1999). Influence of immersion on respiratory requirements during 30-min cycling exercise. *Eur.Respir.J.*, 13, 860-866.

Brosseau L, Balmer S, Tousignat M, O'Sullivan JP, Goudreault C, Goudreault M, Gringas S. (2001). Intra- and intertester reliability and criterion validity of the parallelogram and universal goniometers for measuring maximum active knee flexion and extension of patients with knee restrictions. *Arch Phys Med Rehabil.*, 82, 396-402.

Brown SP, Jordan JC, Chitwood LF, Beason KR, Alvarez JG and Honea KP. Relationship of heart rate and oxygen uptake kinetics during deep water running in the adult population –ages 50 to 70 years. Journal of Aging and Physical Activity 1998; 6: 248-255.

Byrne HK, Craig JN, Willmore JH. (1996). A comparison of the effects of underwater treadmill walking to dry land treadmill walking on oxygen consumption, heart rate and cardiac output. *Journal of Aquatic Physical Therapy.*, 4 , 4-11.

Byrne A and Byrne DG. (1993). The effect on exercise on depression, anxiety and other mood states : a review. *J Psychomatic Research.*, 37, 565-574.

Callahan LF, Pincus T, Huston JW, Brooks RH, Nance EP, Kaye JJ. (1997). Measures of activity and damage in rheumatoid arthritis : depiction of changes and prediction of mortality over five years. *Arthritis Care and Research.*, 10, 381-394.

Callahan LF, Bloch DF, Pincus T. (1992). Identification of work disability in rheumatoid arthritis: physical, radiographic and laboratory variables do not add explanatory power to demographic and functional variables. *J Clin Epidemiol.*, 45, 127-138.

Campion MR. ed. (1990). *Adult hydrotherapy. A practical approach.* Oxford : Heinemann Medical Books.

Charter RA and Nehemkis AM. (1983). The language of pain intensity and complexity: new methods of scoring the McGill Pain Questionnaire. *Perceptual and Motor Skills.*, 56, 519-537.

Choukran M-L and Varene P. (1990). Adjustments in oxygen transport during head-out immersion in water at different temperatures. *J Appl Physiol .*, 68, 1475-1480.

Choukran M-L, Kays C and Varene P. (1989). Effect of water temperature on pulmonary volumes in immersed human subjects. *Respir Physiol.*, 75, 255-266.

Christie JL, Sheldahl LM, Tristani FE, Wann LS, Sagar KB, Levandoski SG, Ptacin MJ, Sobocinski KA and Morris RD. (1990). Cardiovascular regulation during head-out water immersion exercise. *Journal of Applied Physiology.*, 69, 657-664.

Çimen ÖB, Deviron SD, Yorgancioğlu ZR. (2000). Pulmonary function tests, aerobic capacity, respiratory muscle strength and endurance in patients with rheumatoid arthritis. *Clin Rheumatol.*, 20, 168-173.

Cohen R, Bell WH, Saltzmann HA and Kylstra JA. 91971). Alveola-arterial oxygen pressure differences in man immersed up to the neck in water. *J Appl Physiol.*, 30, 720-723.

Connelly TP, Sheldahl LM, Tristani FE, Levandoski SG, Kalkhoff RK, Hoffman MD and Kalbfleisch JH. (1990). Effect of increased central blood volume with water immersion on plasma catecholamines during exercise. *Journal of Applied Physiology.*, 69, 651-656.

Cooper CB, Storer TW. (2001). *Exercise Testing and Interpretation : A Practical Approach.* Cambridge : University Press.

Coruzzi P, Ravanetti C, Musiari L, Biggi A, Vescove PP and Novarini A. (1988). Circulating opioid peptides during water immersion in normal man. *Clinical Science.*, 74, 133-136.

Cox NL and Carr A. (1991). The relationship between range of movement of joints and disability. *British Journal of Rheumatology.* Abstracts Supplement, p4.

Craig AB and Dvorak M. (1968). Thermal regulation of man exercising during water immersion. *Journal of Applied Physiology.*, 25, 28-35.

Craig AB and Dvorak M. (1966). Thermal regulation during water immersion. *J Appl Physiol.*, 21, 1577-1585.

Crane MG and Harris JJ. (1974). Suppression of plasma aldosterone by partial immersion. *Metabolism.*, 23, 359-368.

Crotty M, McFarlane AC, Brooks PM, Hopper JL, Bieri D and Taylor SJ. (1994). The psychosocial and clinical status of younger women with early rheumatoid arthritis: a longitudinal study with frequent measures. *The British Journal of Rheumatology.*, 33, 754-760.

Cureton KJ. (1997). Physiologic responses to water exercise. In : Ruoti RG, Morris DM and Cole AJ. Eds. *Aquatic Rehabilitation*, pp. 39-56. New York : Lippincott.

Danneskiold-Samsoe B, Lynberg K, Risum T and Telling M. (1987). The effect of water exercise therapy given to patients with rheumatoid arthritis. *Scand J Rehab Med.*, 19, 31-35.

Davis BC and Harrison RA. (1988). *Hydrotherapy in Practice.* London : Churchill Livingstone.

DeMaere JM and Ruby BC. (1997). Effects of deep water and treadmill running on oxygen uptake and energy expenditure in seasonally trained cross country runners. *J Sports Med Phys Fitness.*, 37, 175-181.

Derion T, Guy HJB, Tsukimoto K, Prediletto WSR, Poole DC, Knight DR and Wagner PD. (1992). Ventilation-perfusion relationships in the lung during head-out water immersion. *J Appl Physiol.*, 72, 64-72.

Devereaux PJ, Bhandari M, Montori V, Manns BJ, Ghali WA, Guyatt GH. (2002). "Double blind, you are the weakest link – goodbye !". *Evidence-based Nursing.*, 5, 36-37.

Devlin J, Gough A, Huisoon A, Perkins P, Holder R, Reece R, Arthur V, Emery P. (1997). The acute phase and function in early rheumatoid arthritis. C-reactive protein levels correlate with functional outcome. *J Rheumatology.*, 24, 9-13.

Dial C and Windsor RA. (1985). A formative evaluation of a health education water exercise program for class II and III adult rheumatoid arthritis patients. *Patient Education and Counseling.*, 7, 33-42.

Dixon JS and Bird HA. (1981). Reproducibility along a 10cm vertical visual analogue scale. *Annals of the Rheumatic Diseases.*, 40, 87-89.

Downie WW, Leatham PA, Rhind VM, Wright V, Branco JA and Anderson JA. (1987). Studies with pain rating scales. *Annals of the Rheumatic Diseases.*, 37, 378-381.

Dowzer CN, Reilly T and Cable NT. (1998a). Effects of deep and shallow water running on spinal shrinkage. *British Journal of Sports Medicine.*, 32, 44-48.

Dowzer CN and Reilly T. (1998b). Deep-water running. *Sports Exercise and Injury.*, 4, 56-61.

Durnin JVGA, Womersley J. (1974). Body fat assessed from total body density and its estimation from skinfold thickness : measurements on 481 men and women aged from 16 to 72 years. Br J Nutr., 32, 77-97.

Ekblom B, Lovegren O, Alderin M, Fridstrom M and Satterstrom G. (1974). Physical performance in patients with rheumatoid arthritis. *Scand J Rheumatology.*, 3, 121-125.

Ekdahl C, Eman R, Petersson I, Svensson B. (1994). Dynamic training and circulating neuropeptides in patients with rheumatoid arthritis : a comparative study with healthy subjects. *Int. J. Clin. Pharm. Res.*, XIV, 65-74.

Ekdahl C and Broman G. (1992). Muscle strength, endurance, and aerobic capacity in rheumatoid arthritis: a comparative study with healthy subjects. *Annals of the*

Rheumatic Diseases., 51, 35-40.

Ekdahl C, Andersson SI and Svensson B. (1989). Muscle function of the lower extremities in rheumatoid arthritis and osteoarthrosis. *J Clin Epidemiol.*, 42, 947-954.

Elykayam O, Wigler I, Tishler M, Rosenblum I, Caspi D, Segal R, Fishel B, Yaron M. (1991). Effect of spa therapy in Tiberias on patients with rheumatoid arthritis and osteoarthritis. *J Rheumatology.*, 18, 1799-1803.

Epstein M. (1992). Renal effects of head-out water immersion in humans : a 15-year update. *Physiological Reviews.*, 72, 563-621.

Epstein M. (1978). Renal effects of head-out water immersion in man : implications for an understanding of volume homeostasis. *Physiological Reviews.*, 58, 529-581.

Epstein M, Levinson R and Loutzenhiser R. (1976). Effects of water immersion on renal haemodynamics in normal man. *Journal of Applied Physiology.*, 41, 230-233.

Ettinger WH. (2001). Arthritis and related musculoskletal disorders. In : *Resistance Training for Health and Rehabilitation* (JE Graves and BA Franklin, eds). Leeds : Human Kinetics.

Evans BW, Cureton KJ and Purvis JW. (1978). Metabolic and circulatory responses to walking and jogging in water. *Research Quarterly.*, 49, 442-449.

Fehling PC, Smith DL, Warner SE, Dalsky GP. (1999). Comparison of accelerometers with oxygen consumption in older adults during exercise. *Med Sci Sports Exerc.*, 31, 171-175.

Felson DT. (1993). Choosing a core set of disease activity measures for rheumatoid arthritis clinical trials. *The Journal of Rheumatology.*, 20, 531-534.

Fletcher A, Gore S, Jones R, Fitzpatrick R, Spiegelhalter D and Cox D. (1992). Quality of life measures in health care. II: design, analysis and interpretation. *British Medical Journal.*, 305, 1145-1148.

Førre Ø, Haugen M, Hassfeld WG. (2000). New treatment possibilities in rheumatoid arthritis. *Scand J Rheumatol.*, 29, 73-84.

Frangolias DD, Rhodes EC and Taunton JE. (1996). The effect of familiarity with deep water running on maximal oxygen consumption. *J Strength and Conditioning Research.,* 10, 215-219.

Frangolias DD and Rhodes EC. (1995). Maximal and ventilatory threshold responses to treadmill and water immersion running. *Medicine and Science in Sports and Exercise* ., 27, 1007-1013.

Frese E, Brown M, Norton BJ. (1987). Clinical reliability of manual muscle testing, *Physical Therapy.*, 67, 1072-1076.

Fries JF, Spitz PW and Young DY. (1982). The dimensions of health outcomes : the health assessment questionnaire, disability and pain scales. *The Journal of Rheumatology.*, 9, 789-793.

Fries JF, Spitz P, Kraines RG and Holman HR. (1980). Measurement of patients outcome in arthritis. *Arthritis and Rheumatism.*, 23, 137-145.

Gabrielsen A, Videbaek R, Johansen LB, Warberg J, Christensen NJ, Pump B and Norsk P. (2000). Forearm vascular and neuroendocrine responses to graded water immersion in humans. *Acta Physiologica Scandinavica.*, 169, 87-94.

Gajdosik RL and Bohannon RW. (1987). Clinical measurement of range of movement. Review of goniometry emphasizing reliability and validity. *Physical Therapy.*, 67, 1867-1872.

Gaston-Johansson F and Gustafsson M. (1990). Rheumatoid arthritis: determination of pain characteristics and comparison of RAI and VAS in its measurement. *Pain.*, 41, 35-40.

Gehring MM, Keller BA and Brehm BA. (1997). Water running with and without a flotation vest in competitive and recreational runners. *Medicine and Science in Sports and Exercise.,* 29, 1374-1378.

Gerber LH. (1989). Rehabilitation of patients with rheumatic diseases. In : Kelley WN, Harris ED, Ruddy S and Sledge CB,eds. *Textbook of Rheumatology*, pp.1904-1925. London : WB Saunders.

Gerston J. (1955). Effect of ultrasound upon tendon extensibility. *Am J Phys Med.*, 34, 362-9.

Glass B, Wilson D, Blessing D and Miller E. (1995). A physiological comparison of suspended deep water running to hard surface running. J.*of Strength and Conditioning Research.*, 5, 9:17-21.

Gleim GW and Nicholas JA. (1989). Metabolic costs and heart rate responses to treadmill walking in water at different depths and temperatures. *American Journal of Sports Medicine.*, 17, 248-252.

Gleeson NP and Mercer TH. (1996). The utility of isokinetic dynamometry in the assessment of human muscle function. *Sports Med.*, 21, 188-34.

Godfrey K. (1985). Comparing the means of several groups. *N Engl J Med.*, 98, 385-394.

Goldby W and Scott DL. (1993). Editorial. *British Journal of Rheumatology.*, 32, 771-773.

Gogia PP, Braatz JH, Rose SJ and Norton BJ. (1987). Reliability and validity of goniometric measurements of the knee. *Physical Therapy.*, 67, 192-195.

Goodwin J, Clark C, Deakes J, Burdon D, Lawrence C. (1992). Clincial methods of goniometry : a comparative study. *Disability and Rehabilitation.*, 14, 10-15.

Grahame R, Hunt JN, Kitchen S and Gabell A. (1978). The diuretic and natriuretic effects of water immersion - a possible rationale for balneotherapy. *Ann Rheum Dis.*, 37, 567.

Grimes DA and Schulz KF. (2002). An overview of clinical research : the lay of the land. *The Lancet.*, 359, 57-61.

Guillemin F, Constant F, Collin JF and Boulange M. (1994). Short and long-term effect of spa therapy in chronic low back pain. *British Journal of Rheumatology.*, 33, 148-151.

Gunga H-C, Kirsch K. (1989). Water immersion as a tool to study antigravity mechanisms of the human body. Proc. 1st. International Symposium on Head-out Water Immersion, Bristol, September 1989.

HACP. (1990). Hydrotherapy : Standards for good practice. London : Chartered Society of Physiotherapy.

Hakkinen A, Sokka T, Kotaniemi A, Paananen ML, Malkia E, Kautiainen H and Hannonen P. (1999a). Muscle strength characteristics and central bone mineral density in women with recent onset rheumatoid arthritis compared to healthy controls. *Scand J Rheumatol*, 28, 145-151.

Hakkinen A, Sokka T, Kotaniemi A, Kautiainen H, Jappinen I, Laitinen L, Hannonen P. (1999b). Dynamic strength training in patients with early rheumatoid arthritis increases muscle strength but not bone mineral density. *J Rheumatol.*, 26, 1257-1263.

Hakkinen AH, Malkia EA, Sokka TM, Hannonen PJ. (1998). A physically demanding occupation predicts premature retirement among patients with erosive arthritis. *Physiotherapy Theory and Practice.*, 14, 13-22.

Hakkinen A, Hannonen P and Hakkinen K. (1995). Muscle strength in healthy people and in patients suffering from recent-onset inflammatory arthritis. *British Journal of Rheumatology.*, 34, 355-360.

Hakkinen A, Hakkinen K , Hannonen P. (1994). Effects of strength training on neuromuscular function and disease activity in patients with recent-onset inflammatory arthritis. *Scand J Rheumatol*, 23, 237-242.

*Hall J, Blake D and Garbutt G. (2001). Acute physiological effects of exercise in water. *Physical Therapy Reviews.*, 6, 215-229.

*Hall J, Macdonald IA, Maddison PJ and O'Hare JP. Cardiorespiratory responses to underwater treadmill walking in healthy females. Eur J Appl Physiol 1998;77:278-284.

*Hall J, Skevington SM, Maddison PJ and Chapman K. (1996). A randomized and controlled trial of hydrotherapy in rheumatoid arthritis. *Arthritis Care and Research.*, 9, 206-215.

Hall J. (1993). Effects of hydrotherapy in rheumatoid arthritis. MPhil thesis, University of Bath, Bath.

Hall J, Bisson D and O'Hare P. The physiology of immersion. Physiotherapy, 1990, 76, 517-521.

Hanna RD, Sheldahl LM, Tristani FE. (1971) Effect of enhanced preload with head-out water immersion on exercise response in men with healed myocardial infarction. Am J Cardiol., 71, 1041-1044.

Hansen TM, Hansen G, Langgaard AM, Rasmussen JO. (1993). Longterm physical training in rheumatoid arthritis. A randomized trial with different training programs and blinded observers. *Scand J Rheumatol.*, 22, 107-112.

Harkness JAL, Richter MB, Panayi GS, Van de Pette K, Unger A, Pownall R and Geddawi M. (1982). Circadian variation in disease activity in rheumatoid arthritis. *British Medical Journal.*, 284, 551-554.

Harris ED. (1989). The clinical features of rheumatoid arthritis. In : Kelley WN, Harris ED, Ruddy S and Sledge CB, eds. *Textbook of Rheumatology*, pp. 943-981. London : WB Saunders.

Harrison R and Bulstrode S. (1987). Percentage weight-bearing during partial immersion in the hydrotherapy pool. *Physiotherapy Practice*, 3, 60-63.

Hart LE, Tugwell P, Buchanan WW, Norman GF, Grace EM and Southwell D. (1985). Grading of Tenderness as a source of interrater error in the Ritchie Articular Index. *The Journal of Rheumatology.*, 12, 716-717.

Hernández-Cruz B, Cardiel MH. (1998). Intra-observer reliability of commonly used outcome measures in rheumatoid arthritis. *Clinical and Experimental Rheumatology.*, 16, 459-462.

Hill J, Bird HA, Lawton CW and Wright V. (1990). The Arthritis Impact Measurement Scales:an anglicized version to assess the outcome of British patients with rheumatoid arthritis. *British Journal of Rheumatology.*, 29, 193-196.

Hochberg MC, Chang RW, Dwosh I, Lindsey S, Pincus T, Wolfe F. (1992). The American College of Rheumatology 1991 revised criteria for the classification of global functional status in rheumatoid arthritis. *Arthritis and Rheumatism.*, 35, 498-502.

Huntley A, White AR, Ernst E. (2002). Relaxation therapies for asthma: a systematic review. *Thorax.*, 57, 127-131.

Huskisson EC. (1976). Assessment for clinical trials. *Clinics in Rheumatic*

Diseases., 2, 37-49.

Jacobsen E. (1938). *Progressive Relaxation.* Chicago : University of Chicago Press.

Jensen MP, Karoly P and Braver S. (1986) The measurement of clinical pain intensity : a comparison of six methods. *Pain.*, 27, 117-126.

Jette AM. (1985). State of the art in functional status assessment. In : Rothstein JM, ed. *Measurement in Physical Therapy,* pp 137-168. London : Churchill Livingstone.

Jones E, Hanly JG, Mooney R et al. (1991). Strength and function in the normal and rheumatoid hand. *J Rheumatology.*, 18, 1313-1318.

Kazis LE, Anderson JJ, Meenan RF. (1989). Effect sizes for interpreting changes in health status. *Medical Care.*, 27, S178-S189.

Kazdin AE. (1992). *Research Design in Clinical Psychology*, pp.83-92. Massachusetts : Allyn and Bacon.

Kell RT, Bell G, Quinnet A. (2001). Musculoskeletal fitness, health outcomes and qulaity of life. *Sports Med.*, 31, 863-873.

Kelly BT, Roskin LA, Kirkenhall DT and Speer KP. (2000). Shoulder muscle activation during aquatic and dry land exercises in nonimpaired subjects. *J Orthopaedic and Sports Physical Therapy.*, 30, 204-210.

Khosla SS and Dubois AB. (1979). Fluid shifts during the initial phase of immersion diuresis in man. *Journal of Applied Physiology.*, 46, 703-708.

Kim JM and Weisman MH. (2000). When does rheumatoid arthritis begin and why do we need to know ? *Arthritis and Rheumatism.*, 43, 473-484.

Kinnear PR and Gray CD. (1999). *SPSS for Windows Made Simple*, p228. Hove : Psychology Press Ltd.

Komatireddy GR, Leitch RW, Cella K, Browning G, Minor M. (1997). Efficacy of low load resistive muscle training in patients with rheumatoid arthritis functional class II and III. *J Rheumatology.*, 24, 1531-1539.

Lang TA and Secic M. (1997). *How to Report Statistics in Medicine*, pp. 83-84. Pennsylvania : American College of Physicians.

Lawlor D, Hopker SW. (2001). The effectiveness of exercise as an intervention in the management of depression : a systematic review and meta-regression analysis of randomized controlled trials. *British Medical Journal.*, 322, 763-767.

Lee DM and Weinblatt ME. (2001). Rheumatoid arthritis. *Lancet.*, 358, 903-911.

Lee P, Baxter A, Dick WC and Webb J. (1974). An assessment of grip strength measurement in rheumatoid arthritis. *Scand J of Rheumatology.*, 3, 17-23.

Levine JD, Fields HI, Basbaum AI. (1993a). Peptides and the primary afferent nociceptor. *J Neurosci.*, 13, 12273-2286.

Levine J, Taiwo Y. (1993b). Inflammatory pain. In : Wall P, Melzack R (eds). *Textbook of Pain.* London: Churchill Livigstone.

Levy J and Dick WC. (1975). The detection of change in disease activity in patients with rheumatoid arthritis. *Clinics in Rheumatic Diseases.*, 1, 225-243.

Lineker SC, Badley EM, Hawker G, Wilkins A. (2000). Determining sensitivity to change in outcome measures used to evaluate hydrotherapy exercise programs for people with rheumatic diseases. *Arthritis Care and Research.,* 13, 62-65.

Lineker S, Badley E, Charles C, Hart L, Streiner D. (1999). Defining morning stiffness in rheumatoid arthritis. *The Journal of Rheumatology.*, 26, 1052-1057.

Lollgen H, von Nieding G, Krekeller H, Smidt U, Koppenhagen K and Frank H. (1976). Respiratory gas exchange and lung perfusion in man during and after head-out water immersion. *Undersea Biomed Res.*, 3, 49-56.

Lorig K, Chastain L, Ung E. (1989). Development and evaluation of a scale to measure perceived self-efficaxcy in people with arthritis. *Arthritis Rheum.*, 32, 37-44.

Lynberg K, Danneskiold-Samsoe B and Halskov O. (1988). The effect of physical training on patients with rheumatoid arthritis : Changes in disease activity, muscle strength and aerobic capacity. A clinically controlled minimized crossover study. *Clinical and Experimental Rheumatology.*, 6, 253-260.

Main CJ and Waddell G. (1989). The assessment of pain. *Clinical Rehabilitation.*, 3, 267-274.

Mano T. (1990). Sympathetic nerve mechanisms of human adaptation to environment - findings obtained by microneurographic studies. *Environmental Medicine.*, 34, 1-35.

Mason JH, Anderson JJ and Meenan RF. (1988). A model of health status for rheumatoid arthritis. *Arthritis and Rheumatism.*, 31, 714-720.

Mayhew TP and Rothstein JM. (1985). Measurement of muscle performance with instruments. In : Rothstein JM, ed. *Measurement in Physical Therapy*, pp57-102. London : Churchill Livingstone.

McAuley E and Rudolph D. (1995). Physical activity, aging and psychological well-being. *Scholarly Reviews*, 3, 67-96.

McEntegart A, Capell HA, Creran D, Rumley A, Woodward M and Lowe GDO. (2001). Cardiovascular risk factors, including thrombotic variables, in a population with rheumatoid arthritis. *Rheumatology.*, 40, 640-644.

McKeeken J, Stillman B, Story I, Kent P and Smith J. (1999). The effects of knee extensor and flexor muscle training on the timed-up-and-go test in individuals with rheumatoid arthritis. *Physiother Res Int.*, 4, 55-67.

Meenan RF, Mason JH, Anderson JJ, Guccione AA and Kazis LE. (1992). The content and properties of a revised and expanded Arthritis Impact Measurement Scales Health Status Questionnaire. *Arthritis and Rheumatism.*, 35, 1-10.

Meenan RF, Gertman PM and Mason JH. (1980). Measuring health status in arthritis. The Arthritis Impact Measurement Scale. *Arthritis and Rheumatism.*, 23, 146-152.

Melton-Rogers S, Hunter G, Walter J and Harrison P. (1996). Cardiorespiratory responses of patients with rheumatoid arthritis during bicycle riding and running in water. *Physical Therapy.*, 76, 1058-1065.

Melzack R. (1975). The McGill pain questionnaire : major properties and scoring methods. *Pain.*, 1, 277-299.

Melzack R and Wall P. (1988). *The Challenge of Pain.* (2nd Edn). London : Penguin Books.

Michaud TJ, Brennan DK, Wilder RP and Sherman NW. (1995a). Aquarunning and gains in cardiorespiratory fitness. *Journal of Strength and Conditioning Research.*, 9, 78-84.

Michaud TJ, Rodriguez-Zayas J, Andres FF, Flynn MG and Lambert CP. (1995b). Comparative exercise responses of deep-water and treadmill running. *Journal of Strength and Conditioning Research.*, 9,104-109.

Michlovitz SL. (1990). *Thermal Agents in Rehabilitation*, pp.88-108. Philadelphia : FA Davis Co.

Miller PJ. (1985). Assessment of joint motion. In : Rothstein JM, ed. *Measurement in physical therapy*, pp. 103-136. London : Churchill Livingstone.

Minor MA and Hewett JE. (1995). Physical fitness and work capacity in women with rheumatoid arthritis. *Arthritis Care and Research.*, 8, 146-154.

Minor MA, Hewett JE, Webel RR, Anderson SK and Kay DR. (1989). Efficacy of physical conditioning exercise in patients with rheumatoid arthritis and osteoarthritis. *Arthritis and Rheumatism.*, 32, 1396-1405.

Minor MA, Hewett JE, Webel RR, Dreisinger TE and Kay DR. (1988). Exercise tolerance and disease related measures in patients with rheumatoid arthritis and osteoarthritis. *The Journal of Rheumatology.*, 15, 905-911.

Mitarai G, Mano T, Mori S and Jijiwa H. (1972). Electromyographic study on human standing posture in experimental hypogravic state. *Annual report of the research institute of environmental medicine.*, 19,1-9. Nagoya University.

Miwa C, Sugiyama Y, Mano T, Matsukawa T, Iwase S, Watanabe T, Kobayashi. (2000). Effects of aging on cardiovascular responses to gravity-related fluid shifts in humans. *J Gerontol A Biol Sci Med Sci.*, 55, M329-35.

Miwa C, Mano T, Iwase S, Matsukawa T, Sugiyama Y and Koga K. (1996). Aging reduces sympathosupressive response to head-out water immersion in humans. *Acta Physiol Scand.*, 158, 15-20.

Moening D, Scheidt A, Shepardson L and Davies GJ. (1993). Biomechnaical comparison of water running and treadmill running. *Isokinetics and Exercise Science.*, 3, 207-215.

Molenaar E, van der Heijde, Boers M. (2000). Update on outcome assessment in rheumatic disorders. *Current Opinion in Rheumatology.*, 12, 91-98.

Morgan WP. (1994). Physical activity, fitness and depression. In : Bouchard C, Shepherd RJ, Stephen T, eds. *Physical activity, fitness and health: international proceedings and consensus statement.* Champaign, Ill. : Human Kinetics, 851-867.

Myers DB, Grennan DM, Palmer DG. (1980). Hand grip function in patients with rheumatoid arthritis. *Arch Phys Med Rehabil.*, 61, 369-373.

Nakamitsu S, Sagawa S,Miki K, Wada F, Nagaya L,Keil C et al. (1994). Effect of water temperature on diuresis-natriuresis:AVP,ANP and urodilatin during immersion in men. *J Appl Physiol.*, 77, 919-1925.

Nakazawa K, Yano H and Miyashita M. (1994). Ground reaction forces during walking in water. *Med Sport Sci.*, 39, 28-34.

Napoletan JC and Hicks RW. (1995). The metabolic effects of underwater treadmill exercise at two depths. *APTR.*, 3, 9-14.

Neuberger GB, Kasal S, Smith KV, Hassanein R. (1994). Determinants of exercise and aerobic fitness in outpatients with arthritis. *Nursing Research.*, 43, 11-17.

Nguyen M, Revel M, Dougados M. (1997). Prolonged effects of 3 week therapy in a spa resot on lumbar spine, knee and hip osteoarthritis : follow-up after 6 months. A randomised controlled trial. *Br J Rheumatol.*, 36, 77-81.

Noble BJ and Robertson RJ. (1996). *Perceived Exertion*, pp 272-273. Leeds : Human Kinetics.

Nordemar R, Ekblom B, Zachrisson L, Lundqvist K. (1981). Physical training in rheumatoid arthritis : A controlled long-term study. *Scan J Rheumatol.*, 10, 17-23.

Norkin CC, White DJ. (1995). *Measurement of joint motion : a guide to goniometry.* Philadelphia : FA Davis.

Norsk P, Bonde-Petersen F and Warberg J. (1986). Arginine vasopressin, circulation and kidney during graded water immersion in humans. *J Appl Physiol.*, 61, 565-574.

Norsk P, Bonde-Petersen F and Christensen NJ. (1990). Catecholamines, circulation and the kidney during water immersion in humans. *American Journal of Physiology.*, 2, 479-484.

O'Hare JP, Dalton N, Roland JM, Gooding J, Payne B, Walters G and Corrall RJM. (1986). Plasma catecholamine levels during water immersion in man. *Horm.Metab.Res.*, 18, 713-716.

O'Hare JP, Heywood A, Summerhayes C, Lunn G, Evans JM, Walters G, Corrall RJM and Dieppe PA. (1985). Observations on the effects of Bath spa water. *British Medical Journal.*,1 291, 1747-1751.

O'Hare JP, Heywood A, Dodds P, Corrall RJM and Dieppe P. (1984). Water immersion in rheumatoid arthritis. *British Journal of Rheumatology.*, 23, 117-118.

Ollier WE, Harrison B, Symmons D. (2001). What is the natural history of rheumatoid arthritis ? *Best Pract Res Clin Rheumatol.*, 1, 27-48.

Otterness IG. (1994). The value of C-reactive protein measurement in rheumatoid arthritis. *Seminars in Arthritis and Rheumatism.*, 24, 91-104.

Palastanga NP. (1994). Heat and Cold. In : Wells PE, Frampton V and Bowsher D. eds. *Pain management by Physiotherapy,* pp. 177-186. London : Butterworth-Heinemann.

Palmgren N, Jensen GF, Kaae K, Windelin M and Colov HC. (1989). Low-power laser therapy in rheumatoid arthritis. *Lasers in Medical Science.,* 4, 193-196.

Park KS, Choi JK and Park YS. (1999). Cardiovascular regulation during water immersion. *Appl Human Sci.*, 18, 233-241.

Parker J, frank K, Beck N, Finan N, walker S, Hewett JE et al. (1988). Pain in rheumatoid arthritis : relationship to demographic, medical, and psychological factors. *J Rheumatology.*, 15, 433-437.

Partridge REH and Duthie JJR. (1963). Controlled trial of the effect of complete immobilization of the joints in rheumatoid arthritis. *Annals of the Rheumatic Diseases.*, 22, 91-98.

Perloff D, Grim C, Flack J, Frohlich D, Hill M, McDonald M, Morgenstern B. (1993). Human blood pressure. Determination by sphygmomanometry. *Circulation.*, 88, 2460-2470.

Persselin JE.(1991). Diagnosis of rheumatoid arthritis. Medical and laboratory aspects. *Clinical Orthopaedics and Related Research.*, 265, 73-82.

Piha SJ and Voipio-Pulkki L.-M.. (1993). Elevated resting heart rate in rheumatoid arthritis: possible role of physical deconditioning. *British Journal of Rheumatology.*, 32, 212-215.

Pinals RS, Masai AT, Larsen. (1981). Preliminary criteria for clinical remission in rheumatoid arthritis. *Arthritis and Rheumatism.*, 24, 1308-1315.

Pincus T, Sokki T and Wolfe F. (2001). Premature mortality in patients with rheumatoid arthritis : evolving concepts. *Arthritis and Rheumatism.*, 44, 1234-1236.

Pincus T, Brooks RH, Callahan LF. (1991). Reliability of grip strength, walking time and button test performed according to a standard protocol. *J Rheumatol.*, 18, 997-1000.

Pirnay F, Deroanne R and Petit JM. (1977). Influence of water temperature on thermal, circulatory and respiratory responses to muscular work.. *Europ J Appl Physio.*, 37, 129-136.

Plante TG and Rodin J. (1990) Physical fitness and enhanced psychological health. *Current Psychology : Research and Reviews.*, 9, 3-24.

Pollock ML, Gaesser GA, Butcher JD, Despres J-P, Dishman RK, Franklin BA, Garber CG. ACSM position stand on the recommended quantity and quality of exercise for developing and maintaining cardiorespiratory and muscular fintess, and flexibility in adults. *Med Sci Sports Exerc.*, 30, 975-991.

Potts MK and Brandt KD. (1987). Evidence of the validity of the Arthritis Impact Measurement Scales. *Arthritis and Rheumatism* ., 30, 93-6.

Powers SK and Howley ET. (2001). *Exercise Physiology : Theory and Application to Fitness and Performance.* London : McGraw Hill.

Prevoo MLL. Van Riel PLCM, Van'T Hof MA, Van Rojswijk MH, Van Leeuwen MA, Kuper HH, Van de Putte LBA. (1993). Validity and reliability of joint indices. A longitudinal study in patients with recent onset rheumatoid arthritis. British Journal of Rheumatology., 32, 589-594

Prins J and Cutner D. (1999). Aquatic therapy in the rehabilitation of athletic injuries. *Clin Sports Med.*, 18, 447-461.

Rall LC and Roubenoff R. (1996). Body composition, metabolism, and resistance exercise in patients with rheumatoid arthritis. *Arthritis Care and Research.*, 9, 151-156.

Reading AE. (1984). Testing pain mechanisms in persons in pain. In : Way PD and Melzack R, eds. *Textbook of Pain*, Chapter 1.17. Edinburgh : Churchill Livingstone.

Reilly KA, Bird HA. (2001). Prophylactic hydrotherapy. *Rheumatology.*, 40, 4-6.
Rennie DW, diPrampero P and Cerretelli P. (1971). Effects of water immersion on cardiac output, heart rate and stroke volume of man at rest and during exercise. *Med Sport (Roma).*, 24, 223-228.

Rhind VM, Unsworth A and Haslock I. (1987). Assessment of stiffness in rheumatology : the use of rating scales. *British Journal of Rheumatology.*, 26, 126-130.

Rhind V, Bird HA and Wright V. (1980). A comparison of clinical assessments of disease activity in rheumatoid arthritis. *Annals of the Rheumatic Diseases.*, 39, 135-137.

Richardson C, Emery P. (1996). Laboratory markers of disease activity. *J Rheumatology.*, (suppl 44), 23, 23-30.

Rintala P, Kettunen H and McCubbin JA. (1996). Effects of water exercise program for individuals with rheumatoid arthritis. *Sports Med.,Training and Rehab.*, 7, 31-38.

Risch WD, Koubenec H-J, Beckmann U, Lange S and Gauer OH. (1978). The effect of graded immersion on heart volume, central venous pressure, pulmonary blood distribution, and heart rate in man. *Pflugers Arch.*, 374, 115-118.

Ritchie SE and Hopkins WG. (1991). The intensity of exercise in deep-water running. *Int.J.Sports.Med.*, 1, 12:27-29.

Ritchie DM, Boyle JA, McInnes JM, Jasani MK, Dalakos TG, Grieveson P and Buchanan WW. (1968). Clinical studies with an articular index for the assessment of joint tenderness in patients rheumatoid arthritis. *Quarterly Journal of Medicine.*, 147, 393-406.

Rothstein JM, Miller PJ and Roettger RF. (1983). Goniometric reliability in a clinical setting. *Physical Therapy.*, 63, 1611-1615.

Sagawa S, Shiraki K, Yousef K and Konda N. (1988). Water temperature and intensity of exercise in maintenance of thermal equilibrium. *J.Appl.Physiol.*, 65, 2413-2419.

Sakauchi M, Narushima K, Sone H, Kamimaki Y, Kato S, Takita T, Suzuki N, Moro K. (2001). Kinematic approach to gait analysis in patients with rheumatoid arthritis involving the knee joint. *Arthritis Rheum.*, 45, 35-41.

Sandford-Smith S, Mackay-Lyons M and Nunes-Clement S. (1998). Therapetuic benefit of aqaerobics for individuals with rheumatoid arthritis. *Physiotherapy Canada.*, winter, 40-46.

Sangha O. (2000). Epidemiology of rheumatic diseases. *Rheumatology.*, 39 (suppl.2), 3-12.

Schoenfeld-Smith K, Petroski GF, Hewett JE, Johnson JC, Wright GE, Smarr KL, Walker SE, Parker JC. (1996). A biopsychosocial model of disability in rheumatoid arthritis. *Arthritis Care and Research.*, 9, 368-375.

Schultz KF, Chalmers I, Hayes RJ, Altman DG. (1995). Empirical evidence of bias :

dimensions of methodologic quality associated with estimates of treatment effects in controlled trials. *Journal of the American Medical Association.*, 273, 408-412.

Scott JT. (1960). Morning stiffness in rheumatoid arthritis. *Ann Rheum Dis.*, 19, 361-367.

Scott J and Huskisson EC. (1976). Graphic representation of pain. *Pain.*, 2, 175-184.

Schultz KF and Grimes DA. (2002). Generation of allocation sequences in randomised trials: chance, not choice. *The Lancet.*, 359, 515-519.

Semble El, Loeser RF and Wise CM. (1990). Therapeutic exercise for rheumatoid arthritis and osteoarthritis. *Seminars in Arthritis and Rheumatism.*, 20, 32-40.

Sheldahl LM, Tristani FE, Connelly TP, Levandoski SG, Skelton MM and Cowley AW. (1992). Fluid-regulating hormones during exercise when central blood volume is increased by water immersion. *American Journal of Physiology.*, 262, R779-R785.

Sheldahl LM, Tristani FE, Clifford PS et al. (1987). Effect of head-out water immersion on cardiorespiratory responses to dynamic exercise. *J Am Coll Cardiol.*, 10, 1254-1258.

Sheldahl LM, Wann LS, Clifford PS, Tristani FE, Wolf LG and Kalbfleisch JH. (1984). Effect of central hypervolaemia on cardiac performance during exercise. *Journal of Applied Physiology.*, 57, 1662-1667.

Skevington SM . (1990). A standardised scale to measure beliefs about controlling pain (BPCQ) : a preliminary study. *Psychol Health.*, 4, 221-232.

Skevington SM. (1979). Pain and locus of control - a social approach. In : Oborne DJ, Gruneberg M and Eiser JR. eds. *Research and Psychology in Medicine*, Vol 1, pp61-69. London : Academic Press..

Skinner AT, Thompson AM. (1983). *Duffield's Exercise in Water.* (3rd edn.) London: Bailliere Tindall.

Smith JR and Walker KM. (1983). Knee and elbow range of motion in healthy older individuals. *Physical and Occupational Therapy in Geriatrics.*, 2, 31-38.

Smith RD and Polley HF. (1978). Rest therapy for rheumatoid arthritis. *Mayo Clinic Proceedings.*, 53, 141-145.

Solgaard S, Kristiansen B, Jensen JS. (1984). Evaluation of instruments for measuring grip strength.. *Acta Orthop Scand.*, 55, 569-571.

Spiegel JS, Paulus HE, Ward NB, Spiegel TM, Leake B and Kane RL. (1987). What are we measuring? An examination of walk time and grip strength. *The Journal of Rheumatology.*, 14, 80-86.

Sramek P, Simeckova M, Jansky L, Savlikova, Vybiral S. (2000). Human physiological responses to immersion into water of different temperatures. *Eur J Appl Physiol.*, 81, 436-442.

Stenstrom CH, Alexanderson H, Lundberg I, Theodorsson E, Nisell R. (1999). Exercise and variations in neuropeptide concentrations in rheumatoid arthritis. *Neuropeptides.*, 33, 260-264.

Stenstorm CH, Arge B, Sundbom A. (1996). Dynamic training versus relaxation training as home exercise for patients with inflammatory rheumatic diseases. *Scand J Rheumatol.*, 25, 28-33.

Stenstrom CH. (1994a). Therapeutic exercise in rheumatoid arthritis. *Arthritis Care Res*, 7, 190-197.

Stenstrom CH. (1994b). Radiological progression in rheumatoid arthritis functional class II – relations with demographic factors, disease severity and exercise frequency. *Phys Ther.*, 74:32-39.

Stenstrom CH, Lindell B, Swanberg E, Swanberg P, Harms-Ringdahl K and Nordemar R. (1991). Intensive dynamic training in water for rheumatoid arthritis functional class II - a long term study of the effects. *Scand J Rheumatol.*, 20, 358-365.

Stenstrom CH, Lindell B, Swanberg E, Harms-Ringdahl K, Nordemar R. (1990). Functional and psychosocial consequences of disease experience of pain and exertion in a group of rheumatic patients considered for active training. *Scand J Rheumatology.*, 19, 374-382.

Stratford P, Agostino V, Brazeau C, Gowitxke BA. (1984). Reliability of joint angle measurment : a discussion of methodology issues. *Physiotherapy Canada.*, 36 : 5-9.

Strong LH, Gee GK, Goldman RF. (1985). Metabolic and vasomotor insulative responses occurring on immersion in cold water. *J Appl Physiol.*, 58, 964-977.

Sugajimo Y, Mitarai G, Koeda M and Moritani T. (1996). Characteristic changes in motor unit activity in hip joint flexor muscles during voluntary isometric contraction during water immersion. *J Electromyogr Kinesiol.*, 6, 83-95.

Sukenik S, Neumann L, Buskila D, Kleiner-Baumgarten A, Zimlichman S and Horowitz J. (1990a). Sulphur bath and mud pack treatment for rheumatoid arthritis at the Dead sea. *Annals of Rheumatic Diseases.*, 49, 99-102.

Sukenik S, Neumann L, Buskila D, Kleiner-Baumgarten A, Zimlichman S and Horowitz J. (1990b). Dead Sea bath salts for the treatment of rheumatoid arthritis. *Clinical and Experimental Rheumatology.*, 8, 353-357.

Sutej PG and Hadler NM. (1991). Current principles of rehabilitation for patients with rheumatoid arthritis. *Clinical Orthopaedics and Related Research.*, 265, 116-

124.

Sutherland A. (1764). An attempt to ascertain and extend the virtues of Bath and Bristol waters. London : Frederick and Leake.

Svedenhag J and Seger J. (1992). Running on land and in water : comparative exercise physiology. *Medicine and Science in Sports and Exercise.*, 24, 1155-1160.

Taal E, Rasker JJ, Wiegman O. (1996). Patients education and self-management in rheumatic diseases : a self-efficacy approach. *Arthritis Care and Research.*, 9, 229-238.

Tabachnick BG and Fidell LS. (1983). *Using Multivariate Statistics.* New York : Harper and Row Publishers.

Takeshima N, Rogers MR, Watanabe E, Brechue WF, Okada A, Yamada T, Islam MM, Hayano J. (2002). Water-based exercise improves health-related aspects of fitness in older women. Med Sci Sports Exerc., 33, 544-551.

Takeshima N, Nakata M, Kobayashi F, Tanaka K and Pollock ML. (1997). Oxygen uptake and heart rate differences between walking on land and in water in the elderly. *Journal of Aging and Physical Activity.*, 5, 126-134.

Templeton MS, Booth DL, O'Kelly WD. (1996). Effects of aquatic therapy on joint flexibility and functional ability in subjects with rheumatic disease. *JOSPT.*, 23, 376-381.

Thompson PW, Kirwan JR. (1995). Joints count : a review of old and new articular indices of joint inflammation. *British Journal of Rheumatology.*, 34, 1003-1008.

Thompson PW, Hart LE, Goldsmith CH, Spector TD, Bell MJ and Ramsden MF. (1991). Comparison of four articular indices for use in clinical trials in rheumatoid arthritis:patient, order and observer variation. *The Journal of Rheumatology.*, 18, 661-665.

Thompson PW, Silman AJ, Kirwan JR, Currey HLF. (1987). Articular indices of joint inflammation in rheumatoid arthritis. *Arthritis and Rheumatism.*, 30, 618-623.

Town GP and Bradley SS. (1991). Maximal metabolic responses of deep and shallow water running in trained runners. *Medicine and Science in Sports and Exercise* ., 23, 238-241.

van den Ende CHM, Breedveld FC, le Cessie S, Dijkmans BAC, de Mug AW, Hazes JMW. (2000). Effect of intensive exercise on patients with active rheumatoid arthritis: a randomized clinical trial. *Ann Rheum Dis.*, 59, 615-621.

van den Ende CHM, Vliet Vlieland TP, Munneke M and Hazes JM. (1998). Dynamic exercise therapy in rheumatoid arthritis: a systematic review. *Br J Rheumatol.*, 37, 677-687.
van den Ende CHM, Hazes JMW, , le Cessie S, Mulder Wj, Belfor DG, Breedveld

FC, Dijkmans BAC. (1996). Comparison of high and low intensity training in well controlled rheumatoid arthritis. Results of a randomised clinical trial. *Ann Rheum Dis.*, 55, 798-805.

van der Heijde DMFM, van't Hof MA, van Riel PLCM, van de Putte LBA. (1993). Development of a disease activity score based on judgment in clinical practice by rheumatologists. *Journal of Rheumatology.*, 20, 579-581.

van Riel, PLCM, van Gestel AM. (2000). Clinical outcome measures in rheumatoid arthritis. Ann Rheum Dis., 59 (suppl 1), i28-i31.

Verhagen AP, De vet HC, De Bie RA, Boers M van den Brandt PA. (2001). The art of quality assessment of RCTs included in systematic reviews. *J Clin Epidemiol.*, 54, 651-4.

Verhagen AP, de Vet HCW, de Bie RA, Kessels AGH, Boers M and Knipschild PG. Balneotherapy for rheumatoid arthritis and osteoarthritis (Cochrane review). (2000). In : The Cochrane Library, Issue 2. Oxford. Update Software.

Von Diringshofen H. (1948). Die wirkungen des hydrostatischen druckes des wasserbades auf den blutdruck in den kapillaren und dieblindewebseit wasserung. *Z Kreislaufforsch.*, 37, 382-390.

Wadsworth CT, Krishnan R, Sear M, Harrold J, Nielson DH. (1987). Intrarater reliability of manual muscle testing and hand-held dynametric muscle testing. *Physical Therapy.*, 9, 1342-1347.

Wall PD and Melzack R. (1994). *Textbook of Pain.* (3rd edn). Edinburgh : Churchill Livingstone.

Wannamethee SG, Sharper AG. (2001). Physical activity in the prevention of cardiovascular disease. *Sports Med.*, 31, 101-114.

Ward DJ and Tidswell ME. (1984). Rheumatoid arthritis and juvenile chronic arthritis. In : Downie PA, ed. *Cash's textbook of orthopaedics and rheumatology for physiotherapist* pp. 304-347. London : Faber and Faber.

Watkins M. (1993). Evaluation of skeletal muscle performance. In : Harms-Ringdahl K.ed. *Muscle Strength*, pp19-36. London : Churchill Livingstone.

Welsing PMJ, van Gestel AM, Swinkels HL, Kiemeney LALM, van Riel PLCM. (2001). The relationship between disease activity, joint destruction and functional capacity over the course of rheumatoid arthritis. *Arthritis and Rheumatism.*, 44, 2009-2017.

Westby MD, Wade JP, Rangno KK, Berkowitz J. (2000). A randomised controlled trial to evaluate the effectiveness of an exercise program in women with rheumatoid arthritis taking low does prednisone. *J Rheumatol.*, 27, 1674-1690.

Weston CFM, O'Hare JP, Evans JM and Corrall RJM. (1987). Haemodynamic changes in man during immersion in water at different temperatures. *Clinical Science.*, 73, 613-616.

Weyerer S and Kupfer B. (1994). Physical exercise and psychological health. *Sports Med.*, 17, 108-116.

Wilder RP, Brennan D and Schotte DE. (1993). A standard measure for exercise prescription for aquarunning. *American J Sports Medicine.*, 21, 45-48.

Wilkie DJ, Savedra MC, Holzemer WL, Tesler MD, Paul SM. (1990). Use of the McGill Pain Questionnaire to measure pain : a meta-analysis. *Nursing Research.*, 39, 36-41.

Wolfe F, Lassere M, van der Heijde D, Stucki G, Suarez-Almazor M, Pincus T, Eberhardt K et al. (1999). Preliminary core set domains and reporting requirements for longitudinal observational studies in rheumtology. *The Journal of Rheumatology.*, 26, 484-489.

Wolfe F, Mitchell DM, Sibley JT et al. The mortality of rheumatoid arthritis. *Arthritis Rheum.,* 1994; 37, 481-94.

Yamaji K, Greenley M, Northey DR and Hughson RL. (1990). Oxygen uptake and heart rate responses to treadmill and water running. *Canadian Journal of Sports Science* ., 15, 96-98.

Yamazaki F, Endo Y, Torii R, Sagawa S and Shiraki K. (2000). Continuous monitoring of change in hemodilution during water immersion in humans : Effect of water temperature. *Aviation, Space and Environmental Medicine.*, 71, 632-639.

Yelin E, Henke C, Epstein W. (1987). The work dynamics of the person with rheumatoid arthritis. *Arthritis Rheum.*, 30, 507-512.

Yu E, Kitagawa K, Mutoh Y and Miyashita M. (1994). Cardiorespiratory responses to walking in water. *Medicine and Sport Science* ., 39, 35-41.

Appendix 1.1

Classification of Functional Status in RA

Class I Completely able to perform usual activities of daily living (self-care, vocational, and avocational).

Class II Able to perform usual self-care and vocational activities, but limited in avocational activities.

Class III Able to perform usual self-care activities, but limited in vocational and avocational activities.

Class IV Limited in ability to perform usual self-care, vocational, and avocational activities.

Usual self-care activities include dressing, feeding, bathing, grooming, and toileting. Avocational (recreational and/or leisure) and vocational (work, school, homemaking) activities are patient-desired and age- and sex-specific.

Source : Hochberg et al., 1992.

Appendix 4.1

Screening Call

1 Introduction
- personal introduction and purpose of call
- is time available now ?

2 Explanation of what is involved:
- 2 visits to the hospital a week for 4 weeks; between 5 pm and 7 pm (point out that they would only actually spend one hour at the hospital)
- 30-minute care sessions, which may be exercise/relaxation in pool/gym
- 1-hour assessments x 3 (before and after care sessions and 3-months later).

3 Inform availability of next block of care sessions
- clarification of patient's availability (holidays, etc)

4 If agreement to proceed → entry form.

5 If patient appears to be eligible, make appointment for 1st assessment
- tell patient where to come
- remind patient of investigator's name
- ask patient to bring drug bottles/record
- advise patient that the assessment will take approximately 1 hour.

* If patient is without transport, explain that transport cannot be provided at present but that if the situation changes, they will be contacted again.

* If patient is not on stable medication → pending file.

NB Note refusals/not eligibles/pendings in card index file.

Appendix 4.2

Entry Form

ELIGIBLE Yes / No

STUDY NO.

DATE

SURNAME

FIRST NAMES

MR/MRS/MISS/MS/Other:

ADDRESS

PHONE NO. Home:
Work:

DATE OF BIRTH

SEX M/F

AGE

MARITAL STATUS

HOSPITAL NO.

CONSULTANT

GP & ADDRESS

GP letter sent

OCCUPATION

I Self-employed

A With employees:

B Without employees

i) large establishment (>25 employees)

ii) small establishment (<25 employees)

II Employee

A Manager:

B Foreman/supervisor:

i) large establishment (>25 employees)

ii) small establishment (<25 employees)

i) manual work

ii) non-manual work

C Other

III Apprentice IV Family worker V Retired VI Other

RA

Age of onset > 18 yrs	yes/no
Duration of RA	Last bout
RA is primary problem?	yes/no

Which joints are involved?

DRUG THERAPY

Date last changed

Painkillers

NSAIDs

2nd line

Others

Pt agrees to remain on stable medication during trial yes/no

Next clinic appointment

MEDICAL HISTORY

Pt suffers/suffered from:		Details	When	Medication
heart problems	[ ]			
circulatory problems	[ ]			
high blood pressure	[ ]			
paralysis/stroke	[ ]			
epilepsy	[ ]			
diabetes	[ ]			
dizzy spells	[ ]			
bowel/bladder problems	[ ]			
skin problems	[ ]			

AVAILABILITY

Treatments	Monday/Wednesday eve	yes/no
	Tuesday/Thursday eve	yes/no
Assessments	(now, after 4 weeks & after 3 months)	yes/no
Transport to hospital		yes/no

SUITABILITY

Pt has received physiotherapy within the last 30 days	yes/no
Pt has received local or parenteral steroid injection within last 30 days	yes/no
Pt is pregnant	yes/no/na
Pt is taking part in any other trial	yes/no
Pt has problems with stairs	yes/no
: getting dressed and undressed	yes/no
: questionnaire filling	yes/no
Pt has 6 or more involved joints	yes/no
Functional class	I / II / III

Appendix 4.3

Consent Form

A Study to Investigate the Effects of Exercise and Relaxation on Patients with Rheumatoid Arthritis

I, ________________, agree to take part in the research project, the nature of which has been explained to me by ________________.

I understand that:

- I will be asked to take part in eight care sessions, which may involve exercise or relaxation.
- A blood sample will be taken at each of the three assessments.
- I will be asked to complete questionnaires at each of the three assessments.
- If at any time I wish to withdraw, I am perfectly at liberty to do so.

Patient's signature

Researcher's signature

Date

Appendix 4.4 - Exercise Programmes

HYDROTHERAPY EXERCISE PROGRAMME

Equipment required – rubber rings floats (different sizes), table tennis bats.

Warm-up

1. Arm swings – standing with feet apart, swing arms forwards and backwards alternatively. Repeat 10 times with each arm.

2. Trunk rotation – standing with feet apart and holding float on top of the water rotate the trunk from side to side. Repeat 10 times to each side.

3. Step-ups – standing, facing pool step. Step-up with right leg leading 10 times. Repeat with left leg. Use a float to aid balance if required.

4. Repeat the step-up backwards.

5. Trunk side flexion – stand with feet apart, bend to right then left by sliding hand down the outside of the leg. Repeat 10 times to each side.

Leg Exercises

1. Hip flexion and extension – stand facing the wall and holding onto the poolside handrail. With float positioned under the right instep allow the knee and hip to bend than push leg straight and slightly behind. Repeat 10 times. Repeat with left leg.

2. Hip abduction and adduction - stand facing the wall and holding onto the poolside handrail. With float positioned under the right instep raise the leg to the side then pull down. Repeat 10 times. Repeat with left leg.

3. Hip hitching – stand facing the wall. Stand and balance on one leg to a slow count of 10. Change legs. Repeat 10 times.

4. Knee flexion and extension – stand facing the wall and holding onto the poolside handrail. With float positioned under the right thigh, extend knee 10 times. Repeat with other leg.

5. Arm swings - standing with feet apart and holding bats swing arms alternately forwards and backwards. Repeat 10 times. Alter the orientation of the bat depending on arm strength and pain.

6. Arm abduction/adduction - standing with feet apart and arms by side whilst holding bats lift arms out to side, then back. Repeat 10 times. Alter the orientation of the bat depending on arm strength and pain.

7. Shoulder rotation - standing with feet apart flex elbows to 90° and squeeze upper arms into side. Swing lower arm out and in 10 times. May be performed with bats to provide extra resistance.

8. Pronation/supination – adopt the starting position as for Exercise 7. Alternately pronate and supinate forearms. Repeat 10 times. Bats may be used for extra resistance.

9. Elbow extension - a adopt the starting position as for Exercise 7. Alternately extend and flex the elbow. Bats may be used for extra resistance.

10. Upper limb breast stroke - standing with feet apart perform the breast stroke action. Bats may be used for extra resistance.

11. Walking exercises – walk forwards, backwards and sideways to the physiotherapist's command.

12. Free swim – if able.

Progression of Exercises – increase workload by increasing speed (and therefore turbulence), lever arm (bats), buoyancy (floats), breaking surface tension and changing the emphasis of the movement.

LAND EXERCISE PROGRAMME

Equipment required – exercise ball (53cm in dimaeter) , small foam ball and soft football.

Warm-up

1. Arm swings- stand with feet apart, swing arms forwards and backwards alternately10 times.

2. Hip and knee flexion – walk slowly forwards bringing one knee up towards the chest.

3. Trunk rotation – standing with feet apart and arms held out to the side, swing arms around boy whilst trunk rotates to same. Repeat 10 times to each side.

4. Trunk side flexion – stand with feet apart, bend to right then left by sliding hand down the outside of the leg. Repeat 10 times to each side.

Sitting Exercises

1. Sitting to standing – repeat 10 times.

2. Knee flexion/extension – Extend right knee and hold for 10 seconds. Repeat with left leg. Repeat 10 times.

3. Foot rocking – rock forwards and backwards onto toes and heels. Repeat 10 times.

4. Spinal stretching – with stomach pulled in bend forwards towards the floor. Unroll the spine from the base. Repeat 5 times.

5. Wrist circumduction – arms held in front, circle wrists one way then the other.

Mat Exercises

Starting Position – supine or crook lying, head supported by small pillow

1. Arm elevation – hold ball on stomach, lift overhead as far as possible. Repeat 10 times.

2. Arm waving – hold ball above head, move arms to right then left trying to touch the ground. Repeat 10 times.

3. Hip hitching – alternate hip hitching. Repeat 10 times.

4. Hip extension – with legs straight rest feet on the ball, extend spine, hips and knees by pressing down through feet on ball. Repeat 10 times.

5. Bridging – place bent knees on top of ball. Suck in stomach and lift hips off mat. Repeat 10 times.

6. Hip adduction – place foam ball between bent knees and squeeze. Hold for 10 seconds. Repeat 10 times.

7. Hip abduction – lie on side, raise top leg with knee straight slowly upwards. Repat 10 times. Repeat with other leg.

Standing Exercises

1. Walking and bouncing ball – variations on 2 steps forwards and backwards, to the side etc , to physiotherapists command.

2. Ball rolling – round yourself, under each leg, up and down body.

Progression of Exercises – increase intensity by adding free weights, number of repetitions and slowing the movement.

Appendix 4.5 – Range of Movement

RANGE OF MOVEMENT

NAME STUDY NUMBER

ASSESSMENT 1 / 2 / 3 DATE:

WRIST

Left	Extension	________	Total ROM	__________
	Flexion	________		
Right	Extension	________	Total ROM	__________
	Flexion	________		

KNEE

Left	Extension	________	Total ROM	__________
	Flexion	________		
Right	Extension	________	Total ROM	__________
	Flexion	________		

Appendix 4.6 – Grip Strength

GRIP STRENGTH

NAME STUDY NUMBER

DOMINANT HAND: L/R

Assessment 1 Date:

1

2 Average = ____mmHg

3

Assessment 2 Date:

1

2 Average = ____mmHg

3

Assessment 3 Date:

1

2 Average = ____mmHg

3

Appendix 4.7 – Ritchie Index

RITCHIE INDEX

NAME STUDY NUMBER

ASSESSMENT 1 / 2 / 3 DATE:

Temporomandibular joints __________

*Cervical spine __________

Sternoclavicular joints __________

Acromioclavicular joints __________

RIGHT		LEFT
__________	Shoulder	__________
__________	Elbow	__________
__________	Wrist	__________
__________	MCPs	__________
__________	PIPs	__________
__________	*Hip	__________
__________	Knee	__________
__________	Ankle	__________
__________	*Talocalcaneal	__________
__________	*Midtarsal	__________
__________	MTPs	__________

TOTAL JOINT SCORE ________________________

0 = not tender
1 = tender
2 = tender & winced3 = tender, winced & withdrew

* passive mvt

Appendix 4.8 – Morning Stiffness

MORNING STIFFNESS

NAME STUDY NUMBER

Assessment 1 Date:

Are you stiff when you wake up in the morning? Yes/no

If yes, how long does it take for the stiffness to go?

___mins

Assessment 2 Date:

Morning stiffness Yes/no

Duration ___mins

Assessment 3 Date:

Morning stiffness Yes/no

Duration ___mins

Appendix 4.9 - McGill Pain Questionnaire

Please circle the words that best describe your pain over the last month

Jumping	Burning	Cutting	Searing	Itchy
Smarting	Quivering	Wrenching	Numb	Penetrating
Flashing	Pulsing	Splitting	Hot	Stinging
Spreading	Stabbing	Tugging	Shooting	Dull
Aching	Tender	Pulling	Taut	Heavy
Tearing	Hurting	Pounding	Cramping	Radiating
Pressing	Piercing	Tight	Beating	Drawing
Sharp	Crushing	Sore	Boring	Throbbing
Gnawing	Pricking	Tingling	Pinching	Squeezing
Dreadful	Suffocating	Terrifying	Continuous	Unbearable
Agonizing	Sickening	Miserable	Exhausting	Frightful
Troublesome	Intense	Fearful	Vicious	Killing
Punishing	Torturing	Gruelling	Cruel	Wretched
Nauseating	Nagging	Tiring	Annoying	

Appendix 4.10 - Beliefs in Pain Control Questionnaire

Here are some opinions that people sometimes hold about pain. I would like you to read them carefully and show me how much you agree or disagree with each one by ticking one of the numbers for each question. There are no right or wrong answers - I am interested in your views.

		Strongly disagree (1)	Disagree (2)	Mildly disagree (3)	Mildly agree (4)	Agree (5)	Strongly agree (6)
1	If I take good care of myself, I can usually avoid pain.						
2	Whether or not I continue to be in pain in the future depends on the skill of the doctors.						
3	Whenever I am in pain, it is usually because of something I have or have not done.						
4	Being pain-free is largely a matter of luck						
5	No matter what I do, if I am going to be in pain, I will be in pain.						
6	Whether or not I am in pain depends on what the doctors do for me.						
7	I cannot get any pain relief unless I go to seek medical help.						
8	When I am in pain, I know that it is because I have not been taking proper exercise or eating the right food.						
9	Whether or not people are in pain is governed by accidental happenings.						
10	People's pain results from their own carelessness.						
11	I am directly responsible for my pain.						
12	Relief from pain is chiefly controlled by the doctors						
13	People who are never in pain are just plain lucky.						

Appendix 4.11 – McGill Pain and Beliefs in Pain Control Questionnaire Data Collection

McGill Pain Questionnaire

	Assessment 1			Assessment 2			Assessment 3		
	Sensory	Evaluative	Affective	Sensory	Evaluative	Affective	Sensory	Evaluative	Affective
Weighting									
No. of Items									

Beliefs in Pain Control Questionnaire

	Assessment 1	**Assessment 2**	**Assessment 3**
Internal Scale (nos : 1, 3, 8, 10, 11)			
Powerful Doctors (nos : 2, 6, 7, 12)			
Chance Happenings (nos : 4, 5, 9, 13)			

Appendix 5.1

Cardiorespiratory Responses in Normal Females to Land and Water Treadmill Walking

Screening Questionnaire

Please answer all questions. This information is strictly confidential.

Name______________________________ **DOB**____________________

Occupation__________________________

1. Do you consider yourself healthy ? **YES/NO**

2. Are you receiving any current medical treatment or taking any medicines ? **YES/NO**

2b. If YES, what medication(s) are you taking ?

3. Are you or have you been treated for any of the following ?

- High Blood pressure **YES/NO**
- Heart problems **YES/NO**
- Problems with circulation in legs **YES/NO**
- Chest problems **YES/NO**
- Diabetes **YES/NO**
- Kidney Trouble **YES/NO**
- Thyroid trouble **YES/NO**

4. Is there any family history of those illnesses **YES/NO**

4a. If YES please describe

5. Do you have a tendency to faint ?

- on standing **YES/NO**
- in a warm room **YES/NO**

Appendix 5.2

Cardiorespiratory Responses in Normal Females to Land and Water Treadmill Walking

Examination Form

Name________________________________ **Date**______________

Completed by the researcher

6. Systems Enquiry (a "X" indicates there are no problems)

A. Weight loss or gain

B. Appetite

C. Sleep pattern

D. Chest pain : Rest Effort

E. Shortness of breath: Rest Effort

F. Palpitations

G. Leg cramp/pain on walking

H. Ankle swelling

I. Joints

J. Dizzy spells/feelings of faintness

K. Cough/wheeze

L. Abdominal pain

M. Bladder problems

N. Diarrhoea

7. ADNFS Score - what is the most active thing you do ? Establish frequency and duration.

ADNFS score = _________

8. PMHR__________ 85% OF PMHR____________________

9. Height_______m Weight____________kg BMI___________

10. HR and BP

	Lying	Standing	
		1 minute	5 minutes
HR (beats·min^{-1})			
BP (mmHg)			

11. Skin fold measures

Arm circum(cms)	
Waist(cm)	
Hips(cm)	
Biceps(mm)	
Triceps(mm)	
Subscapular(mm)	
Suprailiac(mm)	

12a. Allocate ID_____________________________

12b. Order of expts __________________________

12c. Dates for expts__________________________

Appendix 5.3

Cardiorespiratory Responses to Land and Water Treadmill Walking

Research Consent Form

Please circle the appropriate response.

1. Have you read the patient information sheet ? **YES/NO**

2. Have you had an opportunity to ask questions and discuss this study ? **YES/NO**

3. Have you received satisfactory answers to all your questions **YES/NO**

4. Have you received enough information about this study ? **YES/NO**

5. Who have you spoken to ? ______________________

6. Do you understand that you are free to withdraw from this study :
   - at any time **YES/NO**
   - without having to give a reason for withdrawing **YES/NO**
   - and without affecting your future medical care ? **YES/NO**

7. Do you agree to take part in this study ? **YES/NO**

Signed :__________________Name (print):__________________Date:__________

Researcher's signature____ Date : __________________________(Source : Royal College of Physicians, Guidelines on the practice of ethics committees in medical research involving human subjects, 1990).

Appendix 5.4 - DATA COLLECTION FORM : Normal females

Name________________________ **Date**________________ **85%PMHR**____________

Procedure : WT28(1) / WT36(2) / LT(3)

H_2O Temp : Resevoir__________ **Chamber**___________ **Air temp**_________________ **Pressure**________________ **Humidity**_______________

Mins	BAG No.	SAMPLE VOL	GAS START (l)	GAS FINISH(l)	VOL(l)	%O_2	%CO_2	HR	RPE (legs)	RPE (brthng)	Sf
0-2	____	________	__________	________	__________	________	________	________	_______	________	____
3 - 6											
8 –12											
13 – 17											

Oral temp : Before ex____________ After ex________________

BLOOD PRESSURE

BP -St on Land	**BP - St in water**	**BP - O mins after ex**	**BP - 5 mins after ex (on land)**

Appendix 5.5

Instructions to Subjects for Completing the Rating of Perceived Exertion Scales
(adapted from ACSM guidelines, 1991 and Noble and Robertson,1996)

This a scale of effort or how hard you feel you're working. As you can see the extremes of the scale have descriptions. So, a score of 7 might represent the lowest exertion imaginable whilst a score of 19 would be the greatest effort imaginable.

6
7 very very light
8
9 very light
10
11 fairly light
12
13 somewhat hard
14
15 hard
16
17 very hard
18
19 very very hard
20

During the walking tests we want you to pay close attention to how hard you feel your legs and breathing are working. For each, the feeling should be your total amount of exertion and fatigue, combining all the sensations and feelings of physical stress, effort and fatigue. Don't underestimate or overestimate, just be as accurate as you can and remember there are no right or wrong answers, just how you feel.

Appendix 6.1

Cardiorespiratory Responses in RA Patients to Land and Water Treadmill Walking

Screening Questionnaire

Please answer all questions. This information is strictly confidential.

Name______________________________ **DOB**___________________

Occupation___________________________

1. Do you consider yourself healthy ? **YES/NO**

2. Are you receiving any current medical treatment or taking any medicines ? **YES/NO**

2b. If YES, what medication(s) are you taking ?

Medication Reason

1.

2.

3.

4.

5.

6.

3. Are you or have you been treated for any of the following ?

- High Blood pressure **YES/NO**
- Heart problems **YES/NO**
- Problems with circulation in legs **YES/NO**
- Chest problems **YES/NO**
- Diabetes **YES/NO**
- Kidney Trouble **YES/NO**
- Thyroid trouble **YES/NO**
- Anaemia **YES/NO**

4. Is there any family history of those illnesses **YES/NO**

4a. If YES please describe

5. Do you have a tendency to faint ?

- on standing **YES/NO**

- in a warm room **YES/NO**

6a. Do you smoke ? **YES/NO**

6b. If YES how many do you smoke a day

7a. Have you recently been admitted to hospital ? **YES/NO**

7b. If YES why ?

8a. Have you recently been ill? **YES/NO**

8b. If YES what with ?

Appendix 6.2

Cardiorespiratory Responses in RA Patients to Land and Water Treadmill Walking

Examination Form

Name________________________________ **Date**______________

Completed by the researcher

1. **Systems Enquiry** (a "X" indicates there are no problems)

A. Weight loss or gain

B. Appetite

C. Sleep pattern

D. Chest pain : Rest Effort

E. Shortness of breath: Rest Effort

F. Palpitations

G. Leg cramp/pain on walking

H. Ankle swelling

I. Joints

J. Dizzy spells/feelings of faintness

K. Cough/wheeze

L. Abdominal pain

M. Bladder problems

N. Diarrhoea

O. Blood lipid profile

2. Have you had any operations in the past ?

3. ADNFS Score - what is the most active thing you do ? Establish frequency and duration.

ADNFS score = __________

4. PMHR__________ 85% OF PMHR____________________

5. Height_______m Weight__________kg BMI___________

6. HR and BP

	Lying	Standing	
		1 minute	5 minutes
HR (beats·min^{-1})			
BP (mmHg)			

7. Duration of RA(months) ___________

8. Duration of early morning stiffness(mins)_____________________

9. Ritchie score_________________

10. Functional class______________

11. Joints involved now

12. VAS for pain

No pain ____ **Maximum**
excruciating **pain**

Appendix 6.3 - DATA COLLECTION FORM : Patients with RA

NAME________________________ DATE _______________ 85%PMHR______________ ID___________

Procedure : LT / WT H_2O Temp : Reservoir_______ Chamber (beginning)________End___________

Air temp (before)__________________ Pressure (before)________________ Humidity (before)______________ Oral Temp: Before ex___________

Air temp (after)___________________ Pressure (after)________________ Humidity (after)_______________ Oral Temp: After ex___________

Mins	Bag No	Sample vol	Vol + sample vol	%O2	%CO2	Exp gas temp (C)	HR	RPE (legs)	RPE (brthng)	Sf	Hand Position
0-2											
3 - 6											
8 –12											
13 – 17											

Knee ROM (ext-flex)	RIGHT	LEFT		BP -St on Land	BP - St in water	BP - O mins after ex	BP - 5 mins after ex (on land)
Before ex							
After ex							

Pain before ex : No pain ____ Maximum excruciating pain

Pain after ex :No pain ____ Maximum excruciating pain

A Randomized and Controlled Trial of Hydrotherapy in Rheumatoid Arthritis

Jane Hall, Suzanne M. Skevington, Peter J. Maddison, and Kate Chapman

Objective. *The aim of this study was to evaluate the therapeutic effects of hydrotherapy which combines elements of warm water immersion and exercise. It was predicted that hydrotherapy would result in a greater therapeutic benefit than either of these components separately.*

Method. *One hundred thirty-nine patients with chronic rheumatoid arthritis were randomly assigned to hydrotherapy, seated immersion, land exercise, or progressive relaxation. Patients attended 30-minute sessions twice weekly for 4 weeks. Physical and psychological measures were completed before and after intervention, and at a 3-month followup.*

Results. *All patients improved physically and emotionally, as assessed by the Arthritis Impact Measurement Scales 2 questionnaire. Belief that pain was controlled by chance happenings decreased, signifying improvement. In addition, hydrotherapy patients showed significantly greater improvement in joint tenderness and in knee range of movement (women only). At followup, hydrotherapy patients maintained the improvement in emotional and psychological state.*

Conclusions. *Although all patients experienced some benefit, hydrotherapy produced the greatest improvements. This study, therefore, provides some justification for the continued use of hydrotherapy.*

Key words. *Evaluation; Hydrotherapy; Rheumatoid arthritis; Warm water; Exercise.*

INTRODUCTION

The beneficial use of water in the treatment of joint complaints was advocated by Hippocrates, cultivated by the Romans, exploited by the spa enthusiasts of the Eighteenth Century, and channelled toward contemporary practice as a result of the World Wars, when exercise was included in an attempt to speed up soldiers' recovery. Today, hydrotherapy remains a useful tool in the physiotherapist's armory, and favorable claims made on its behalf are upheld by many patients (1), many of whom have rheumatoid arthritis (RA). The use of exercises in warm water is promoted because of the physical properties of the water, namely, buoyancy and temperature. The weight-relieving property of water immersion allows easier movement with less pain, which may also be attributed to the warmth of the water. However, despite its impressive history and continuing popularity, the efficacy of hydrotherapy in the treatment of RA has not been adequately evaluated.

Literature about the efficacy of hydrotherapy in the treatment of RA is scarce, prompting one investigator to propose practical difficulties and high financial cost as primary deterrents to its evaluation (2). Despite this, other investigators have risen to the challenge. Hydrotherapy has been shown to increase muscle strength (3), increase joint range of movement (2), improve aer-

Funded by the Arthritis and Rheumatism Council and the Chartered Society of Physiotherapy.

Jane Hall, MPhil, MCSP, GradDipPhys, Research Physiotherapist, Royal National Hospital for Rheumatic Diseases; Suzanne M. Skevington, PhD, FBPPsS, Senior Lecturer, School of Social Sciences, University of Bath, and Senior Research Fellow, Royal National Hospital for Rheumatic Diseases; Peter J. Maddison, MD, FRCP, Professor of Bone and Joint Medicine, University of Bath, and Consultant Rheumatologist, Royal National Hospital for Rheumatic Diseases; and Kate Chapman, MSc (Health Psychol), MSc (Clin Psychol), BSc, Research Officer, School of Social Sciences, University of Bath, and Royal National Hospital for Rheumatic Diseases, Bath, UK.

Address correspondence to Jane Hall, Physiotherapy Department, Royal United Hospital, Combe Park, Bath BA1 3NG, UK.

Submitted for publication May 8, 1995; accepted in revised form February 20, 1996.

0893-7524/96/$5.00

obic capacity (4), reduce pain (2,4), and improve function (2–4). The common theme underlying these studies is the benefit of enhanced psychological function, which deserves fastidious attention in future studies (2,4,5). While these studies offer important insights into the use of water exercise, the conclusions remain equivocal, and to date, randomized, controlled trials using appropriate controls and measurement techniques have not been forthcoming. Hydrotherapy is an expensive procedure and, on economic grounds alone, demands serious evaluation.

Hydrotherapy may be defined in terms of two important components: warm water immersion and exercise. The relative contributions of each to the overall therapeutic benefit should be questioned given recent research findings. In a randomized study comparing a group receiving 3 weeks of spa therapy to a waiting list control group, Guillemin et al showed that in the short term (26 days), the effects of a course of hot underwater showers (36°C) had positive effects on a range of outcome measures—pain intensity and duration, lumbar stiffness, disability, and drug consumption—in 98 patients with chronic low back pain (6). Furthermore, with the exception of disability, these improvements were maintained over 9 months. Here, the effects of warm water per se are beneficial for some musculoskeletal disorders. Additionally, the immersion model, which was initially developed to study the physiological effects of weightlessness, has prompted questions about the authenticity of the ostensible rationale for hydrotherapy. Immersion to the suprasternal notch in warm water (35°C) results in a cascade of physiological reactions including diuresis, natriuresis, and inhibition of the sympathetic nervous system (7–10). The basis for these physiological effects is considered to be the hydrostatic pressure, which forces approximately 700 ml of blood from the lower extremities to the central compartment. Distension of the volume receptors by this central hypervolemia is regarded as the trigger for the physiological effects (7–10).

The present study was designed to test the hypothesis that the combined effects of water immersion and exercise in hydrotherapy are therapeutically superior to either used singly.

PATIENTS AND METHODS

Design. A 4-cell parallel design was used. Following initial assessment, patients were randomly assigned by an independent coordinator to 1 of the 4 groups: hydrotherapy or 1 of the 3 comparison groups of seated immersion, land exercise, or progressive relaxation. Random assignment was achieved using a random numbers table and groups of subjects in blocks, so that equal numbers of subjects were allocated to each of the 4 groups (11).

Subjects. In order to estimate the sample size, data from the pilot study were used. The mean pre- to post-difference and standard deviation for the Ritchie articular index (5.0 ± 9.4), together with alpha set at 0.05 and power at 0.8, showed that a sample size of 140 would be required (35 per group) (12).

One hundred forty-eight patients with chronic RA (13) who met Steinbrocker functional class I, II, or III (14) were recruited from outpatient clinics at the Royal National Hospital for Rheumatic Diseases (Bath, UK). Nine patients dropped out prior to the post-test, and all were replaced except for one who withdrew following a myocardial infarction at the end of the data collection period. Reasons for sample attrition included transportation difficulties, shortage of time, and lack of interest. Thus, 139 patients completed the study, with the land exercise group consisting of 34 patients.

Inclusion and exclusion criteria. Only those patients who presented with involvement of at least 6 joints and who were maintained on a stable drug regimen for a period of 30 days in the case of nonsteroidal antiinflammatory drugs (NSAIDs) or 3 months for disease-modifying antirheumatic drugs (DMARDs) were included in the trial. Patients who had received intraarticular corticosteroid injections or physiotherapy treatment within 30 days of assessment for the study were excluded, as were patients who had joint replacement surgery within 6 months. Patients with a history of any known condition contraindicating exercise therapy or immersion in water (i.e., recent myocardial infarction, uncontrolled epilepsy, fear of water) were also excluded.

Procedure. All interventions took place in the gymnasium or hydrotherapy pool at the Royal National Hospital for Rheumatic Diseases. Patients were convened in small groups of 4 or 5. Three physiotherapists were trained to carry out the standardized exercise regimen, relaxation program, and other interventions. In accordance with standard therapeutic practice, the exercise sessions lasted for 30 minutes: the other interventions were designed to last an equivalent length of time. Evidence from the pilot study suggested that 8 sessions of hydrotherapy and land exercise would constitute a suitable course and be in line with existing clinical practice. For reasons of patient fatigue, all interventions were limited to 2 sessions per week. Patients attended for 4 consecutive weeks.

Exercises designed to increase the range of movement of the key joints, namely, shoulder, elbow, wrist, hand, hip, knee, ankle, and foot, and to improve muscle strength of the main upper and lower limb groups were used for the two exercise groups (hydrotherapy and land exercise). The type, duration, and frequency of the exercises were standardized in consultation with the physiotherapists, and the speed and resistance were adjusted by the therapist in response to the individual's capabilities and progress.

An adapted and updated version of Jacobsen's progressive relaxation technique (15), including some mental imagery tasks, was tailored for use with arthritis patients in the two non-exercise groups (seated immersion and progressive relaxation). At each session, the physiotherapist read from a relaxation script following relaxation training. The progressive relaxation group relaxed in a quiet, darkened room on comfortable mats or exercise couches; patients could use pillows to support their heads and knees. The seated immersion group relaxed in the pool on weighted chairs with their legs dependent, in water at approximately 36°C, immersed to the suprasternal notch.

Assessments. The measurements detailed below were taken on 3 occasions: before and after the course, and at the 3-month followup. They were carried out by an independent assessor who was blind to the intervention condition. Patients were assessed on each occasion at the same time of day to control for diurnal variations. The patients and the relevant physiotherapist also completed evaluations before, during, and after the course.

Physical measures. *The Ritchie articular index.* The Ritchie articular index was used to assess joint tenderness (16). The index has been shown to be sensitive to change in previous studies evaluating the efficacy of physiotherapy treatments (4,5,17). Additionally, the intra-rater reliability has been shown to be acceptable (18), and the test is quick and easy to perform. Scores range from 0 to 78.

Morning stiffness. Morning stiffness is characteristic of RA, and variations in its duration are regarded as reflections of change in disease activity. Patients were asked to report the average duration of their morning stiffness (in minutes) as experienced over the previous 2 weeks.

Grip strength. Grip strength was included both as a functional and disease activity measure (19,20). Under standardized conditions, the grip strength of the dominant hand was measured using a digital grip strength monitor inflated to 20 mm Hg. The mean of 3 readings was recorded.

Active range of movement. Wrist and knee active range of movement in flexion and extension was evaluated using a standard goniometer. These 2 joints were selected on the basis of the exercises performed, and the relative ease and reliability of measurement (21,22).

C-reactive protein (CRP). CRP, an acute-phase reactant, is used routinely to monitor disease activity in RA. A high level (above 10 mg/liter) is associated with active inflammatory joint disease. At each assessment, a 5-ml sample of blood was taken. Serum samples were frozen at −20°C within 2 hours of collection, and were subsequently tested in a single batch.

Pain measures. *The McGill Pain Questionnaire (MPQ).* The MPQ (23) assesses the quantitative and qualitative aspects of pain. A shorter version of this questionnaire (24) adapted for use with RA was self-administered. This allowed patients unrestricted choice from 69 adjectives covering sensory, evaluative, and affective dimensions. A number of indices can be derived from the results, but for this study, the weighted values for each of the 3 dimensions were divided by the number of words chosen in that category (25); a low number indicates mild pain and a high number indicates severe pain.

The Beliefs in Pain Control Questionnaire (BPCQ). Previous research has suggested that beliefs about controlling pain may be as important in controlling pain as the pain control itself (26). Additionally, there is some evidence that strong beliefs in internal or personal pain control are more often associated with better physical and psychological health than beliefs that pain is beyond personal control or is external (27). The BPCQ (28) has been standardized for use with patients with chronic RA and is relatively reliable and valid. Its 13 items constitute 3 subscales. The internal scale measures beliefs that pain is within one's personal control; so, a high score indicates strong internality. The other 2 scales measure beliefs that pain is controlled by factors which are beyond or outside one's personal control: the powerful doctors scale examines beliefs that pain control is in the hands of the doctors, and the chance happenings scale evaluates beliefs that pain is controlled by chance happenings or misfortune. High scores reflect high externality of each of these dimensions.

Health status measures. *The Arthritis Impact Measurement Scales 2 (AIMS2).* The original AIMS questionnaire (29) was designed to assess health status in patients with rheumatic diseases. It has been found to be a reliable, valid measure that is sensitive to clinical change (30–32). The revised and expanded version of the self-administered questionnaire, the AIMS2 (33), is divided into 12 subscales: mobility level, walking and bending, hand and finger function, arm function, self-care tasks, household tasks, social activity, support from family and friends, arthritis pain, work, level of tension, and mood. Additional sections concern satisfaction with function, attribution of problems to arthritis, comorbidity, and designation of priority areas for improvement. Because it was anticipated that many of the patients in the study would be retired and/or their main form of work would be in the home, the work subscale of the AIMS2 was adapted to differentiate between employment and housework by the addition of 4 questions in which "housework" was substituted for the original "paid work." While a reliable and valid abbreviated version of the AIMS is available, it lacks sensitivity to changes in mobility, pain, anxiety, and depression (34), and was therefore rejected for use in this study.

To ensure its suitability for use with a British patient population, the language and spelling used in the questionnaire were anglicized according to the work done by Hill et al (35) on the original instrument. Following normalization of the scores according to the method devised by Meenan et al (29), a low number indicates less impact of arthritis.

Evaluation of interventions. Patients' and physiotherapists' perceptions of the interventions were monitored throughout the study, using quantitative techniques.

Patients' view of the intervention. Patients rated the course for effectiveness and enjoyment, using 2 separate scales. These were 5-point scales anchored by "not at all effective," which scored 1 on the scale, and "totally effective," which scored 5. These Likert-type scales were completed on 4 occasions: pre- and posttest to examine whether patient expectations were met, and twice during the course (after the fourth and eighth sessions).

Patients' view of the therapists. At the end of all 8 sessions, patients also completed 5 rating scales which evaluated their therapist on a range of characteristics. Each scale was scored 1–5, anchored at 1 point and 5 points as follows: warm–cold; caring–not caring; well-informed–lack of knowledge; interested–not interested; and enthusiastic–not enthusiastic.

Therapists' view of the patients. To find out whether the therapists' expectations of success for the intervention could affect patient outcomes, the physiotherapists rated each patient after the first and last sessions, according to their expectations of the effectiveness of the intervention. A 9-point scale (maximum adverse effect = 1, maximum benefit = 9) was used.

Statistical methods. In this study we examined the hypothesis that hydrotherapy would give significantly more therapeutic benefit than the interventions consisting of the components of water or exercise alone. Data were analysed using the Statistics Package for the Social Sciences.

A factorial between-and-within subjects multivariate analysis of covariance (MANCOVA) design with repeated measures and for unweighted means was used to compare the 4 groups over the 3 time periods, and in relation to the covariates of disease duration, age, and education. To satisfy MANCOVA assumptions about the number of cases in relation to the number of dependent variables, the dependent variables were divided into 3 groups of conceptually related measures for separate analysis (36). The first group considered the physical variables of the Ritchie articular index, grip strength, and wrist and knee range of movement; the second examined the pain variables from the MPQ and the BPCQ, and the third consisted of the 5 composite health status scales from the AIMS2 questionnaire (31).

Data screening. Prior to the MANCOVA, the data was checked for compliance with the assumptions of this statistical test. Box plots and tests for multivariate normality were carried out on all dependent variables. Non-normal variables were log-transformed (e.g., disease duration, education, and grip strength) or square rooted (e.g., physical component scale of the AIMS2). Conventional methods of dealing with outliers were used in accordance with the usual procedures (36). Where appropriate, some variables were aggregated to

Table 1. The sociodemographic characteristics of the 4 intervention groups

Group	Males : females	Age, mean (SD) years	Disease duration, mean (SD) years	Functional class I	Functional class II	Functional class III	Ritchie index, mean (SD)
Hydrotherapy	14:21	55.8 (12.5)	9.7 (7.7)	9	21	5	21.3 (10.6)
Seated immersion	11:24	58.7 (11.3)	12.2 (9.2)	5	28	2	19.9 (8.9)
Land exercise	8:26	58.5 (11.0)	11.9 (8.2)	3	24	7	21.8 (0.5)
Progressive relaxation	10:25	59.8 (9.3)	12.2 (9.6)	9	19	7	21.4 (9.1)

Table 2. Changes in physical variables, by study group, mean (SD) values

	Overall (n = 139)			Hydrotherapy (n = 35)			Seated immersion (n = 35)			Land exercise (n = 34)			Progressive relaxation (n = 35)		
	Pre	Post	Followup	Pre	Post	Followup	Pre	Post	Followup	Pre	Pst	Followup	Pre	Post	Followup
Ritchie articular	21.15	17.3*	18.1	21.3	15.5†	17.9	19.9	16.8	18.2	21.8	18.9	21.4‡	21.4	18.1	19.5
index	(9.7)	(9.4)	(10.9)	(10.6)	(9.4)	(12.8)	(8.9)	(9.7)	(9.3)	(10.5)	(9.2)	(9.7)	(9.1)	(9.6)	(11.2)
Knee range of	249.1	251.4	252.1	248.4	252.4	252.2	248.1	252.3	254.9	250.8	248.7	248.8	249.0	251.9	252.8
movement, degrees	(25.6)	(26.4)	(24.1)	(25.9)	(27.0)	(23.5)	(27.4)	(25.7)	(26.3)	(25.9)	(28.1)	(25.7)	(24.6)	(28.5)	(21.7)
Wrist range of	167.4	172.1	174.3	178.5	181.8	186.8	170.9	179.9	176.7	161.2	166.8	171.3	158.3	159.6	161.9
movement, degrees	(60.3)	(59.9)	(58.8)	(54.7)	(55.0)	(54.5)	(56.4)	(59.6)	(63.9)	(68/0)	(60.9)	(59.2)	(62.5)	(64.2)	(58.4)
Grip strength,	140.4	142.6	138.9	145.8	152.5	152.2	134.8	141.7	126.6	143.9	142.0	137.9	137.5	134.2	137.3
mm Hg	(75.6)	(75.5)	(70.6)	(77.5)	(77.9)	(70.5)	(62.5)	(60.5)	(50.3)	(92.0)	(99.0)	(91.9)	(71.1)	(61.5)	(63.3)
Morning stiffness,	41.2	36.9	33.9	39.0	39.1	35.3	40.9	39.1	31.0	33.8	27.2	24.1	50.3	41.4	44.5
minutes	(50.7)	(51.1)	(46.4)	(48.6)	(58.0)	(49.3)	(50.5)	(57.8)	(33.9)	(43.9)	(36.6)	(36.8)	(58.9)	(51.8)	(59.9)

* At post-test, joint tenderness was significantly lower than at pre-test ($F = 9.68$, $df = 1, 108$, $P = 0.002$).
† Hydrotherapy patients had the greatest reduction in joint tenderness between pre- and post-test ($F = 5.05$, $df = 1, 109$, $P = 0.03$).
‡ Land exercise patients maintained a significant improvement in joint tenderness at followup ($F = 4.9$, $df = 1, 112$, $P = 0.03$).

Table 3. Changes in knee range of movement and affect, by sex, mean (SD) values

	Overall (n = 139)			Hydrotherapy (n = 35)			Seated immersion (n = 35)			Land exercise (n = 34)			Progressive relaxation (n = 35)		
	Pre	Post	Followup	Pre	Post	Followup	Pre	Post	Followup	Pre	Post	Followup	Pre	Post	Followup
Knee range of movement															
Men	245.4	249.2	248.1	244.8	245.2	243.6	235.4	243.4	243.8	254.8	256.3	253.7	246.6	252.0	251.7
	(26.8)	(28.2)	(24.6)	(23.9)	(24.3)	(23.4)	(35.4)	(34.4)	(31.3)	(27.8)	(28.1)	(24.4)	(20.3)	(26.0)	(19.5)
Women	250.7	252.6	254.1	250.7	257.3*	257.9	252.5	255.3	258.7	249.4	246.1	247.1	249.9	251.9	252.7
	(25.8)	(26.3)	(24.0)	(27.6)	(28.3)	(22.4)	(23.4)	(22.2)	(24.1)	(25.8)	(28.3)	(26.6)	(26.5)	(26.4)	(23.0)
Affect, Arthritis Impact Measurement Scales 2															
Men	2.87	2.89	2.85	3.5	3.5	2.98	2.9	2.8	2.9	1.9	2.2	2.2	3.2	3.0	3.37
	(1.5)	(1.5)	(1.2)	(1.5)	(1.8)	(1.6)	(1.8)	(1.5)	(1.4)	(1.5)	(1.4)	(1.1)	(1.4)	(1.6)	(0.8)
Women	3.5	3.04†	3.0	3.6	3.2	3.03	3.4	3.05	3.1	3.5	3.03	2.9	3.3	2.9	3.1
	(1.3)	(1.3)	(1.3)	(1.4)	(1.5)	(1.5)	(1.1)	(1.0)	(1.1)	(1.4)	(1.3)	(1.5)	(1.5)	(1.2)	(1.3)

* Women receiving hydrotherapy had significantly increased knee range of movement between pre- and post-test ($F = 3.98$, $df = 1, 98$, $P = 0.049$).
† At post-test, women reported the greatest improvement in affect scores ($F = 5.8$, $df = 1, 109$, $P = 0.02$).

provide conceptually viable composites and to accommodate abnormal distributions. The evaluative and affective scales of the MPQ were integrated, in line with previous research (25). Also, the physical variables of right and left knee range of movement and right and left wrist range of movement were summed. Distributions of the AIMS2 subscales tended to be abnormal, and so, the 5 composite scales recommended by Meenan et al were used, since they exhibited relatively normal distributions (33). The physical component scale required square root transformation.

Morning stiffness and CRP failed to satisfy the normality requirements for multivariate analysis and were therefore excluded from parametric analysis. These 2 variables were examined using the Kruskal-Wallis nonparametric test.

Following additional tests for linearity, homoscedasticity, and multicollinearity, some covariates were removed from the analyses. Multicollinearity was a particular problem for education, income, and occupation; on statistical grounds, education was selected as the most representative of the 3.

Pearson correlation coefficients were used to examine relationships between variables of interest over the 3 assessments. Thus, a range of correlations is reported.

Patients' views of the interventions. Separate analyses of variance (ANOVAs) with repeated measures were used on the effectiveness and enjoyment rating scales.

The 5 scales, which related to the patients' views of their therapists, were subjected to principal components analysis. This revealed a single factor (eigenvalue = 4.2) that accounted for 83.4% of the variance and included all 5 scales. Factor scores were high, ranging from 0.89 (caring) to 0.76 (informative). In view of the 1-factor solution, it was not possible to rotate the data to obtain a varimax solution. A one-way ANOVA using the factor scores was employed to test for group differences.

Therapists' views of intervention effectiveness. The therapists' perceptions of effectiveness between the interventions at pre-test were examined using a one-way ANOVA. Pre- and post-test rating scales were compared within each intervention group using paired t-tests.

RESULTS

Sample characteristics. Of the 139 patients with chronic RA who completed the study, 96 were women and 43 were men; their mean age was 58.2 years (SD 11.1). The patients had a disease duration of 11.5 years (SD 8.7), and 66% were in Steinbocker functional class II, indicating that despite a "handicap of discomfort or limited motion at one or more joints," the patients were able to function adequately for normal activities (14). Table 1 details some of the demographic features, showing that the intervention groups were comparable.

At the pre-test interview, 29.5% of patients reported one or more comorbidities on the AIMS2 questionnaire. These mainly related to cardiorespiratory problems (e.g., high blood pressure, asthma, angina). As these patients were evenly distributed throughout the intervention groups, no attempt was made to control for comorbidity in the analysis.

At baseline 73% of patients were prescribed DMARDs and 83% NSAIDs; 5.8% were taking oral steroids. The patients and their physicians were asked to maintain the type and dosage of pre-entry medications as far as was ethically possible during the study period. At each assessment, patients were questioned about their current medications. Ninety-seven percent of patients had been able to maintain pre-entry medications at post-test. By followup, this number had dropped to 79%, and 12.2% required an intraarticular corticosteroid injection. Changes in drugs and requirements for intraarticular injections were evenly spread throughout the intervention groups.

Is the effect of hydrotherapy significantly better than the other conditions? *Physical variables.* When hydrotherapy was compared with the other conditions for the group of physical variables, all patients, regardless of intervention, showed significant improvements in joint tenderness between pre- and post-test, as measured by the Ritchie index (from 21.15 to 17.3, $P = 0.002$). Hydrotherapy patients had the greatest reduction in joint tenderness, with a mean decrease of 27% between pre- and post-test (from 21.3 to 15.5, $P = 0.03$) (Table 2).

Analysis by sex showed that in women who received hydrotherapy, the total combined knee range of movement had significantly increased by 6.6° by the end of the course ($P = 0.049$). Although this improvement was maintained at followup, it was no longer statistically significant (Table 3).

Grip strength, wrist range of movement, duration of morning stiffness, and CRP levels did not change significantly.

Pain variables. All patients demonstrated a significant reduction in their evaluative/affective pain scores between pre- and post-test ($P = 0.005$), but this was not maintained at followup. There were no significant changes in sensory pain.

All patients reported significant pre- to post-test reductions in the belief that pain is controlled by chance happenings or misfortune ($P = 0.049$) (Table 4), but this was not maintained at followup. No differences in

Table 4. Changes in pain variables, by study group, mean (SD) values*

	Overall (n = 139)			Hydrotherapy (n = 35)			Seated immersion (n = 35)			Land exercise (n = 34)			Progressive relaxation (n = 35)		
	Pre	Post	Follow-up	Pre	Post	Follow-up	Pre	Post	Follow-up	Pre	Post	Follow-up	Pre	Post	Follow-up
Sensory pain	2.48	2.59	2.45	2.55	2.64	2.46	2.4	2.7	2.45	2.53	2.57	2.5	2.4	2.4	2.4
(MPQ)	(0.6)	(0.7)	(0.8)	(0.6)	(0.7)	(0.8)	(0.6)	(0.7)	(0.8)	(0.6)	(0.7)	(0.7)	(0.7)	(0.6)	(0.8)
Evaluative/															
affective pain	2.16	1.8†	2.0	2.63	2.1	2.06	2.4	1.9	2.06	2.1	1.3	1.7	1.6	1.8	2.3
(MPQ)	(1.7)	(1.5)	(1.8)	(1.7)	(1.8)	(1.8)	(1.9)	(1.6)	(1.7)	(1.6)	(1.2)	(1.6)	(1.5)	(1.4)	(2.0)
Internal scale	2.7	2.6	2.7	2.6	2.74	2.8	2.8	2.75	2.7	2.6	2.5	2.6	2.8	2.6	2.6
(BPCQ)	(0.8)	(0.8)	(0.8)	(0.8)	(0.7)	(0.7)	(0.8)	(0.9)	(0.8)	(0.8)	(0.7)	(0.8)	(0.8)	(0.8)	(0.7)
Powerful doctors	3.8	3.89	3.96	3.9	3.85	3.87	3.9	3.9	4.06	3.7	3.8	3.75	3.87	3.96	4.1
(BPCQ)	(0.9)	(0.9)	(0.9)	(1.2)	(1.1)	(1.1)	(0.8)	(0.9)	(0.8)	(0.9)	(1.0)	(0.9)	(0.8)	(0.9)	(0.9)
Chance happenings	3.44	3.37‡	3.3	3.46	3.47	3.4	3.5	3.3	3.2	3.4	3.2	3.1	3.48	3.5	3.65
(BPCQ)	(0.9)	(0.9)	(0.9)	(1.0)	(0.8)	(0.9)	(0.8)	(0.8)	(0.7)	(0.9)	(0.8)	(0.8)	(0.9)	(0.9)	(1.0)

* MPQ = McGill Pain Questionnaire; BPCQ = Beliefs in Pain Control Questionnaire.
† All patients reported a reduction in evaluative/affective (MPQ) between pre- and post-test ($F = 8.2$, $df = 1, 118$, $P = 0.005$).
‡ All patients reported a reduction in beliefs that pain was controlled by chance happenings between pre- and post-test ($F = 3.96$, $df = 1, 109$, $P = 0.049$).

the patients' beliefs in pain control by powerful doctors and in the personal control of pain (internal scale) were noted between groups or over time.

For patients in the hydrotherapy group, there were no additional benefits in terms of pain relief or beliefs concerning pain.

Health status measures—AIMS2. All patients significantly improved their physical capacity (by 4.8%) after treatment ($P = 0.007$), and further improvement was noted on this outcome measure at followup ($P = 0.008$) (Table 5).

Significant improvement in mood and tension occurred for all patients after treatment, as represented by a reduction in affect scores ($P = 0.003$). Furthermore, women reported the greatest improvement ($P = 0.02$) (Table 3). At followup, all patients continued to show significant improvement in mood and tension ($P = 0.001$). However, patients receiving hydrotherapy demonstrated the greatest effect ($P = 0.03$) (Table 2).

These two AIMS2 scales, physical capacity and affect, were positively and significantly correlated at all assessments (P values between 0.01 and 0.001), suggesting that physical and psychological well-being are closely related.

No differences between groups or over time were observed in the social or work subscales.

Table 5. Changes in scores on the Arthritis Impact Measurement Scales 2 variables, by group, mean (SD) values

	Overall (n = 139)			Hydrotherapy (n = 35)			Seated immersion (n = 35)			Land exercise (n = 34)			Progressive relaxation (n = 35)		
	Pre	Post	Follow-up	Pre	Post	Follow-up	Pre	Post	Follow-up	Pre	Post	Follow-up	Pre	Post	Follow-up
Physical capacity*	2.57	2.4	2.4	2.3	2.25	2.1	2.4	2.2	2.1	2.7	2.4	2.5	2.9	2.7	2.8
	(1.8)	(1.9)	(1.9)	(1.9)	(2.1)	(1.8)	(1.5)	(1.7)	(1.7)	(2.1)	(1.9)	(2.1)	(1.8)	(1.9)	(1.7)
Affect†	3.3	3.0	2.9	3.5	3.3	3.0	3.2	2.98	3.0	3.2	2.8	2.7	3.3	2.9	3.2
	(1.4)	(1.3)	(1.3)	(1.4)	(1.6)	(1.5)	(1.3)	(1.2)	(1.2)	(1.5)	(1.3)	(1.4)	(1.4)	(1.3)	(1.2)
Social	3.4	3.52	3.54	3.6	3.5	3.6	3.4	3.4	3.5	3.38	3.5	3.4	3.39	3.5	3.6
	(1.1)	(1.2)	(1.3)	(1.2)	(1.3)	(1.3)	(1.2)	(1.2)	(1.2)	(1.2)	(1.3)	(1.4)	(1.0)	(1.1)	(1.1)
Pain‡	4.48	4.47	4.49	4.9	4.8	4.8	4.3	4.3	4.5	4.1	3.8‡	3.8	4.5	4.8	4.7
	(2.2)	(2.2)	(2.3)	(2.2)	(2.7)	(2.5)	(2.2)	(2.2)	(2.4)	(1.9)	(1.8)	(1.9)	(1.9)	(1.9)	(2.2)
Work	3.17	2.8	2.97	3.05	2.4	2.8	2.79	2.8	2.5	3.09	3.1	3.3	3.1	2.9	3.2
	(2.3)	(2.2)	(2.3)	(1.9)	(1.9)	(2.5)	(2.3)	(2.3)	(2.1)	(2.8)	(2.3)	(2.7)	(2.2)	(2.2)	(2.0)

* Physical capacity increased significantly at post-test for all patients ($F = 7.6$, $df = 1, 115$, $P = 0.007$); the improvement in physical capacity was maintained at followup for all patients ($F = 7.3$, $df = 1, 113$, $P = 0.008$).
† Levels of mood and tension decreased for all patients at post-test ($F = 9.3$, $df = 1, 113$, $P = 0.003$); the improvement in the affect scores was maintained at followup for all patients ($F = 10.8$, $df = 1, 112$, $P = 0.001$). At followup, hydrotherapy patients had significantly lower affect scores compared to the other groups ($F = 4.6$, $df = 1, 112$, $P = 0.03$).
‡ At post-test, land exercise patients had significantly less pain compared to other groups ($F = 4.2$, $df = 1, 105$, $P = 0.04$).

Other group findings. No additional benefits were observed for patients receiving seated immersion. Patients in the land exercise group were the only patients to maintain their improvement in overall joint tenderness between post-test and followup ($P = 0.03$). In addition, these patients had a significant reduction in pain on the AIMS2 between pre- and post-test ($P = 0.04$) (Table 2). However, this was not maintained at followup, and, as with the other patients in the study, there was a slight but significant increase in pain on this scale ($P = 0.04$). Despite the overall finding that affective/evaluative pain decreased significantly in the sample as a whole between pre- and post-test, the progressive relaxation group actually experienced a 12.5% increase in their pain ($P = 0.02$), and this persisted at followup ($P = 0.028$). Additionally, beliefs that pain is controlled by chance happenings were found to have been strengthened in the progressive relaxation group at followup (from 3.48 to 3.65, $P = 0.015$).

Perceptions of the interventions. *Patients' views.* All groups reported similar perceptions of the effectiveness of the interventions at pre-test, which did not change significantly over time. This score was high, with overall mean ratings (on a 1–5 scale) of 3.6 (SD 0.9) at pre-test and 3.4 (SD 1.15) at post-test. Similarly, ratings on intervention enjoyment were stable between groups and over time. At pre-test, the overall mean rating was 4.5 (SD 0.7), and at post-test, 4.7 (SD 0.6). A positive and significant correlation between effectiveness and enjoyment was observed at post-test ($r = 0.35$, degrees of freedom [df] = 110, $P = 0.0001$), suggesting that enjoyable treatment may be effective treatment.

All patients, regardless of the intervention, considered their therapist to be relatively warm, caring, informative, interested, and enthusiastic. Patients' views of intervention effectiveness were not significantly correlated with their views of the therapist ($r = 0.08$, df = 110, $P = 0.2$). However, patients' enjoyment of the intervention was significantly and positively correlated with their view of the therapist at all time points (P values range from 0.05 to 0.001).

Therapists' views. At the start of the study, therapists expected that patients in the seated immersion group would benefit more than those in the land exercise group ($F = 3.06$, df = 3, $P = 0.03$). This view was maintained throughout the study period ($t = -1.35$, df = 120, $P = 0.2$).

DISCUSSION

The present study shows that hydrotherapy has value-added benefits for the physical and emotional aspects of rheumatoid arthritis. These occur in addition to the physical and psychological benefits of "placebo attention" seen in all the intervention groups used in this study. The results suggest an enhancement effect in the interaction between exercise and the water, with minor emphasis on the former.

While all groups experienced improved joint tenderness over the 4 weeks, the hydrotherapy group experienced the most relief. This confirms reports by previous investigators, who noted improvement in clinically active joints after a pool program but not after a land program (4). Given that joint tenderness and pain may be similar constructs (37), it seems plausible, within the terms of current theory about pain, that the warmth of the water facilitates a closure of the "gate" in the spinal cord, and in enhancing the blood flow, relieves the pain (38). Given that hydrotherapy is used as a pain-relieving treatment, it is surprising that it was only the land exercise patients, who in addition to reductions in evaluative/affective pain (in common with other groups), experienced a similar reduction in pain scores on the AIMS2. However, as these 2 variables are significantly and positively correlated at all time points, it seems likely that both were measuring similar aspects of the pain experience ($r = 0.25$–0.41, $P \leq 0.05$–0.01). An alternative theory is that the reduced joint tenderness seen in the hydrotherapy group may be attributed to the reduction of joint loading occasioned by the buoyancy. In addition, the hydrostatic pressure of water immersion is considered to reduce edema (39), and this may have been one of the factors in decreasing joint tenderness and increasing range of movement. The unexpected finding that the increase in knee range of movement was gender-specific may be due to the small number of men in the sample, which despite adjustment for the unequal numbers in the analysis, did not provide the most robust test of this feature. Further studies should seek to test an equal number of men and women. It may also be related to the severity of edema at study entry. Due to the unreliability of available measures, knee swelling was not assessed, and it is therefore unknown whether women presented with greater edema than did men, and hence had greater capacity for improvement. Given that significant and negative correlations were noted between the Ritchie articular index and knee range of movement ($r = 0.43$–0.63, $P \leq 0.05$–0.01), this finding may be important for future trials.

The finding that mood and tension, measured by the affect scale (AIMS2), were significantly enhanced at followup in hydrotherapy patients is also worth comment, particularly because significant positive correlations were noted between the Ritchie index at post-test and affect at followup ($r = 0.63$, $P \leq 0.001$). It therefore seems plausible that improvements in tenderness which occurred by the end of treatment but which were not altogether maintained at followup 3 months later, may have primed improvements in mood which had already begun by the end of treatment. While a causal relationship cannot be established by correlations, these findings are in line with some results from cognitive therapy, which show that psychological improvement often takes longer to develop than physiological change, and tends to follow it. This appears to demonstrate that important psychological changes may follow physiotherapy treatments and it is one of the values of longitudinal studies that include the measurement of psychological variables. Given that a recent paper showed psychosocial variables to be as important as disease and pain in determining function, this is an extremely important finding (40).

The finding that the seated immersion group had no benefits additional to those found in the other groups confirms the hypothesis that the exercise component of hydrotherapy is of central importance. Additionally, the finding that the progressive relaxation group had increased evaluative/affective pain at post-test and followup, whereas the exercising and seated immersion groups had decreased pain at post-test, supports the theory that both components of hydrotherapy are required for effective benefit. The finding that chance happenings scores were higher at followup in the progressive relaxation group cannot be attributed to similar increases in pain, as these 2 variables were not significantly correlated in this group. It is therefore difficult to explain why relaxation on land strengthens beliefs that pain is controlled by misfortune. This finding is all the harder to explain in view of the findings that patients in the progressive relaxation group enjoyed their course equally as well as those in the other groups, liked their therapist as much, and judged their progress to be equally efficacious.

This study represents the largest examination, to date, of hydrotherapy and its components in patients with RA. While quantitative improvement was small, but nonetheless significant, the clinical significance needs to be addressed. The literature suggests that demonstrable objective improvement with hydrotherapy is small (2–4). Stenström et al noted few significant differences between a hydrotherapy training and a control group (5). The authors suggest that limitations of present outcome measures are a factor, given the patients' enthusiasm to participate. In the study reported here, responses from hydrotherapy patients suggested that the water and the exercise together increased their confidence to move freely. A further influence on the outcome may be the limited duration of treatment, and extending the treatment time may have resulted in greater therapeutic effect. Future studies examining both the therapeutic effects and the mediating actions are required to address these current limitations.

In conclusion, this controlled trial investigating the effects of hydrotherapy—a combination of water and exercise—showed that hydrotherapy gave superior benefits in terms of physical and psychological functioning compared to the benefits experienced simply as a result of participation in the study. While these results are moderate in effect, they provide some justification for continuing investment in this type of treatment.

Grateful thanks are extended to Fiona Phillips, Rebecca Cox, and John Porter for carrying out the treatments; to Alison White and Ruth Clevely for poolside support; and to Trish Myers for secretarial and administrative support. The help and support from staff in the Physiotherapy Department at the Royal National Hospital for Rheumatic Diseases is gratefully acknowledged. We thank Sally Jones and Julian Sims in the School of Social Sciences, Bath University, for computing support. We also thank the patients who gave a great deal of their time to take part in the study.

REFERENCES

1. Campion MR: Adult Hydrotherapy: A Practical Approach. Oxford, Heinemann Medical Books, 1990
2. Dial C, Windsor RA: A formative evaluation of a health education-water exercise program for class II and III adult rheumatoid arthritis patients. Patient Educ Counseling 7:33–42, 1985
3. Danneskiøld-Samsøe B, Lynberg K, Risum T, Telling M: The effect of water exercise therapy given to patients with rheumatoid arthritis. Scand J Rehab Med 19:31–35, 1987
4. Minor MA, Hewett JE, Webel RR, Dreisinger TE, Kay DR: Exercise tolerance and disease related measures in patients with rheumatoid arthritis and osteoarthritis. J Rheumatol 15:905–911, 1988
5. Stenström CH, Lindell B, Swanberg E, Swanberg P, Harms-Ringdahl K, Nordemar R: Intensive dynamic training in water for rheumatoid arthritis functional class II—a long-term study of effects. Scand J Rheumatol 20:358–365, 1991
6. Guillemin F, Constant F, Collin JF, Boulange M: Short and long-term effect of spa therapy in chronic low back pain. Br J Rheumatol 33:148–151, 1994
7. Epstein M: Renal effects of head-out water immersion in humans: a 15 year update. Physiol Rev 72:563–621, 1992
8. O'Hare JP, Heywood A, Summerhayes C, Lunn G, Evans JM, Walters G, Corrall RJM, Dieppe PA: Observations on the effects of immersion in Bath spa water. BMJ 291: 1747–1751, 1985
9. Mano T: Sympathetic nerve mechanisms of human adaptation to environment—findings obtained by microneurographic studies. Environ Med 34:1–35, 1990

10. Weston CFM, O'Hare JP, Evans JM, Corrall RJM: Haemodynamic changes in man during immersion in water at different temperatures. Clin Sci (Colch) 73:613–616, 1987
11. Kazdin AE: Research Design in Clinical Psychology. Second edition. Boston, Allyn and Bacon, 1992
12. Altman DG: Practical Statistics for Medical Research. London, Chapman and Hall, 1991
13. Arnett FC, Edworthy SM, Bloch DA, et al: The American Rheumatism Association 1987 revised criteria for the classification of rheumatoid arthritis. Arthritis Rheum 31:315–324, 1988
14. Steinbrocker O, Traeger CH, Batterman RC: Therapeutic criteria in rheumatoid arthritis. JAMA 140:659–662, 1949
15. Jacobsen E: Progressive Relaxation. Chicago, University of Chicago Press, 1938
16. Ritchie DM, Boyle JA, McInnes JM, Jasani MK, Dalakos TG, Grieveson P, Buchanan WW: Clinical studies with an articular index for the assessment of joint tenderness in patients with rheumatoid arthritis. QJM 147:393–406, 1968
17. Sukenik S, Neumann L, Buskila D, Kleiner-Baumgarten A, Zimlichman S, Horowitz J: Sulphur bath and mud pack treatment for rheumatoid arthritis at the Dead Sea. Ann Rheum Dis 49:99–102, 1990
18. Levy J, Dick WC: The detection of change in disease activity in patients with rheumatoid arthritis. Rheum Dis Clin North Am 1:225–243, 1975
19. Lee P, Baxter A, Dick EC, Webb J: An assessment of grip strength measurement in rheumatoid arthritis. Scand J Rheumatol 3:17–23, 1974
20. Rhind V, Bird HA, Wright V: A comparison of clinical assessments of disease activity in rheumatoid arthritis. Ann Rheum Dis 26:126–130, 1987
21. Gogia PP, Braatz JH, Rose SJ, Norton BJ: Reliability and validity of goniometric measurements at the knee. Phys Ther 67:192–195, 1987
22. Rothstein JM, Miller PJ, Roettger RF: Goniometric reliability in a clinical setting. Phys Ther 63:1611–1615, 1983
23. Melzack R: The McGill Pain Questionnaire: major properties and scoring methods. Pain 1:277–299, 1975
24. Skevington SM: Pain and locus of control—a social approach. In, Psychology and Medicine. Vol. 1. Edited by DJ Oborne, M Gruneberg, JR Eiser. London, Academic Press, 1979
25. Charter RA, Nehemkis AM: The language of pain intensity and complexity: new methods of scoring the McGill Pain Questionnaire. Percept Mot Skills 56:519–537, 1983
26. Bowers KS: Pain, anxiety and perceived control. J Consult Clin Psychol 32:596–602, 1968
27. Phares EJ: Locus of Control in Personality. New Jersey, General Learning Press, 1976
28. Skevington SM: A standardised scale to measure beliefs about controlling pain (BPCQ): a preliminary study. Psychol Health 4:221–232, 1990
29. Meenan RF, Gertman PM, Mason JH: Measuring health status in arthritis: the Arthritis Impact Measurement Scales. Arthritis Rheum 23:146–152, 1980
30. Meenan RF, Anderson JJ, Kazis LE, Egger MJ, Altz-Smith M, Samuelson CO Jr, Willkens RF, Solsky MA, Hayes SP, Blocka KL, Weinstein A, Guttadauria M, Kaplan SB, Klippel J: Outcome assessment in clinical trials: evidence for the sensitivity of a health status measure. Arthritis Rheum 27:1344–1352, 1984
31. Potts MK, Brandt KD: Evidence of the validity of the Arthritis Impact Measurement Scales. Arthritis Rheum 30:93–96, 1987
32. Anderson JJ, Firschein HE, Meenan RF: Sensitivity of a health status measure to short-term clinical changes in arthritis. Arthritis Rheum 32:844–850, 1989
33. Meenan RF, Mason JH, Anderson JJ, Guccione AA, Kazis LE: AIMS2: the content and properties of a revised and expanded Arthritis Impact Measurement Scales health status questionnaire. Arthritis Rheum 35:1–10, 1992
34. Lorish CD, Abraham N, Austin JS, Bradley LA, Alarcón GS: A comparison of the full and short versions of the Arthritis Impact Measurement Scales. Arthritis Care Res 4:168–173, 1991
35. Hill J, Bird HA, Lawton CW, Wright V: The Arthritis Impact Measurement Scales: an anglicized version to assess the outcome of British patients with rheumatoid arthritis. Br J Rheumatol 29:193–196, 1990
36. Tabachnick BG, Fidell LS: Using Multivariate Statistics. Second edition. New York, Harper Collins, 1989
37. Gaston-Johansson F, Gustafsson M: Rheumatoid arthritis: determination of pain characteristics and comparison of RAI and VAS in its measurement. Pain 41:35–40, 1990
38. Melzack R, Wall P: The Challenge of Pain. New York, Penguin Books, 1988
39. Von Diringshofen H: Die Wirkungen des hydrostatischen Druckes des Wasserbades auf den Blutdruck in den Kapillaren und die Bindegewebsentwasserung. Z Kreislaufforsch 37:382–390, 1948
40. Crotty M, McFarlane AC, Brooks PM, Hopper JL, Bieri D, Taylor SJ: The psychosocial and clinical status of younger women with early rheumatoid arthritis: a longitudinal study with frequent measures. Br J Rheumatol 33:754–760, 1994

Eur J Appl Physiol (1998) 77: 278–284

ORIGINAL ARTICLE

J. Hall · I.A. Macdonald · P.J. Maddison
J.P. O'Hare

Cardiorespiratory responses to underwater treadmill walking in healthy females

Accepted: 3 September 1997

Abstract This study compared the cardiorespiratory responses of eight healthy women (mean age 30.25 years) to submaximal exercise on land (LTm) and water treadmills (WTm) in chest-deep water (Aquaciser). In addition, the effects of two different water temperatures were examined (28 and 36°C). Each exercise test consisted of three consecutive 5-min bouts at 3.5, 4.5 and 5.5 km · h^{-1}. Oxygen consumption ($\dot{V}O_2$) and heart rate (HR), measured using open-circuit spirometry and telemetry, respectively, increased linearly with increasing speed both in water and on land. At 3.5 km · h^{-1} $\dot{V}O_2$ was similar across procedures [χ = 0.6 (0.05) l · min^{-1}]. At 4.5 and 5.5 km · h^{-1} $\dot{V}O_2$ was significantly higher in water than on land, but there was no temperature effect (WTm: 0.9 and 1.4, respectively; LTm: 0.8 and 0.9 l · min^{-1}, respectively). HR was significantly higher in WTm at 36°C compared to WTm at 28°C at all speeds, and compared to LTm at 4.5 and 5.5 km · h^{-1} ($P \leq 0.003$). The HR-$\dot{V}O_2$ relationship showed that at a $\dot{V}O_2$ of 0.9 l · min^{-1}, HR was higher in water at 36°C (115 beats · min^{-1}) than either on land (100 beats · min^{-1}) or in water at 28°C (99 beats · min^{-1}).
The Borg scale of perceived exertion showed that walking in water at 4.5 and 5.5 km · h^{-1} was significantly harder than on land (WTm: 11.4 and 14, respectively; LTm: 9.9 and 11, respectively; $P \leq 0.001$). These cardiorespiratory changes occurred despite a slower cadence in water (the mean difference at all speeds was 27 steps/min). Thus, walking in chest-deep water yields higher energy costs than walking at similar speeds on land. This data has implications for therapists working in hydrotherapy pools.

Key words Head-out water immersion · Walking exercise · Oxygen consumption · Effects of temperature · Stride frequency

J. Hall (✉)
Physiotherapy Department, Royal United Hospital, Bath, BA1 3NG, UK

I.A. Macdonald
Department of Physiology and Pharmacology, University of Nottingham Medical School, Queen's Medical Centre, Nottingham, NG7 2UH, UK

P.J. Maddison
Department of Rheumatology, Ysbyty Gwynedd Bangor, Gwynedd, LL57 2PW, UK

J.P. O'Hare
Department of Biological Sciences, University of Warwick, Coventry, CV4 7AL, UK

Introduction

Hydrotherapy, exercise in warm water, remains a popular modality and is favoured by therapists and patients because of the buoyancy effect which reduces loading, and hence pain, on the lower limbs (Hall et al. 1996). In addition to specific exercises for mobility and strength, physiotherapists are increasingly incorporating a cardiovascular training element to their therapeutic programmes. Recently, in the UK, an underwater treadmill (Aquaciser) has become available. This allows walking/running in water at various depths (from ankle- to chest-deep), thus allowing the correction of functional walking patterns in a gravity-reduced environment. In addition, its small size allows the water temperature to be individualised quickly and easily. Prior to its use on patients we compared the metabolic responses of underwater treadmill walking to land treadmill walking in healthy females. Furthermore, following concerns regarding the possible heat stress resulting from aquarobic activity in therapeutic pools, we studied a range of temperature extremes (28–36°C). It was hypothesised that oxygen consumption ($\dot{V}O_2$) would be higher during water walking compared to land walking at the same speed because of the drag effect, and that the heart rate (HR) would be lower in water at 28°C than at 36°C due to differences in thermal load.

Methods

Subjects

Eight healthy volunteer females with a mean age of 30.25 years completed a screening interview, examination and familiarisation period before giving their informed consent to take part in this study. Subjects were screened on the basis of a standard health questionnaire and resting HR and blood pressure (BP). No subject reported having had a recent acute illness, and all were free from chronic diseases. The study was approved by the local ethics committee. Subjects had a mean (SD = 0.035) height of 1.67 m, a body mass of 63.25 (1.46) Kg, a body mass index of 22.69 (1.5), and a body fat level of 26.66 (1.4)%.

Protocol

All subjects were unfamiliar with treadmill walking and therefore a pilot study was conducted to examine the practise time required for a reliable technique to be adopted. Three exercise sessions of 10 min duration were sufficient for the subjects to feel comfortable. In addition, HR data from the final familiarisation session showed no differences between minutes 5–10, suggesting that a steady-state had been achieved and that subjects were habituated in their technique. Therefore all subjects in the present study completed three familiarisation sessions, both in the water and on the land treadmills, the week before embarking on the study. Practise with the mouthpiece and Hans-Rudolph valve was also given.

After familiarisation all subjects completed three treadmill tests (land, water at 28.2°C ± 0.06 and water at 35.8°C ± 0.08) which were randomly allocated, and the order of experiments was balanced between the subjects. Each test was similar. After a 2-min warm-up period subjects completed three consecutive bouts of 5 min duration at progressively increasing speeds (3.5, 4.5 and 5.5 km · h^{-1}). These speeds were selected on the basis of pilot studies which showed that subjects run in water at a slower speed (approximately 6 km · h^{-1}) than on land. In addition, stride frequency (S_f) during water running is significantly less than in land running at similar speeds, probably because of the resistance afforded by the water. The fastest walking speed in water was observed to be 5.5 km · h^{-1} and therefore the range of walking speeds was chosen to represent slow, moderate and fast walking. During the water treadmill tests subjects were immersed to the level of the xiphoid process, and the water was heated to either 28.2°C or 35.8°C. Subjects were asked to walk with a reciprocal arm swing.

All exercise tests were carried out 2 h post-prandially and subjects were asked to refrain from drinking tea and coffee and from smoking during the morning of the test. All procedures were completed in the morning between 9.00 a.m. and 12.00 p.m. and during the follicular phase of the subjects' menstrual cycle (Lebrun et al. 1995). The air temperature of the laboratory during the study was between 21°C and 25°C and the humidity was between 35 and 58%.

Measurements

Expired gas was collected via open-circuit spirometry using a Hans-Rudolph valve and Douglas bags for the final 2 min of each exercise bout. Gas samples were analysed using an infrared carbondioxide analyser (PK Morgan 901), and a paramagnetic oxygen analyser (OA 250 Servomex). HR was measured in the final minute of each exercise bout using HR monitors (Polar Favor^{TM} HR monitors), as were ratings of perceived exertion (RPE) using Borg's 6–20 scale for breathing and legs separately (Borg 1982). S_f was measured for 60 s in the 4th min of each exercise bout. BP, measured immediately before and after the exercise session with the left arm held horizontal at the level of the heart, was recorded using a manual sphygmomanometer. Because we were unable to make measurements of core body temperature we recorded sublingual temperature before and after the exercise session to ensure that no major changes had occurred. No baseline differences in sublingual temperature were noted, suggesting that all subjects were within the follicular phase of their menstrual cycle. None of the subjects showed changes in temperature of greater than 1°C.

Statistical analyses

All values are expressed as the mean (SEM). Differences between land and water, and between speed and water temperature were examined using two-way analyses of variance. When variables were unaffected by water temperature the mean of the hot and cold water was used in the statistics. The level of statistical significance was set at $P < 0.05$.

Results

$\dot{V}O_2$, ventilation ($\dot{V}_E$) and HR increased linearly with speed during both water and land walking. $\dot{V}O_2$ and $\dot{V}_E$ were not affected by water temperature (Fig. 1 and Table 1). At 4.5 and 5.5 km · h^{-1} $\dot{V}O_2$ and $\dot{V}_E$ were significantly higher in water than on land ($P \leq 0.012$ and ≤ 0.03, respectively; $\dot{V}O_2$: water 0.9 and 1.4 l · min^{-1}; land 0.76 and 0.95 l · min^{-1}, respectively). The respiratory exchange ratio (R) increased significantly with speed during both water and land walking ($P = 0.0001$)

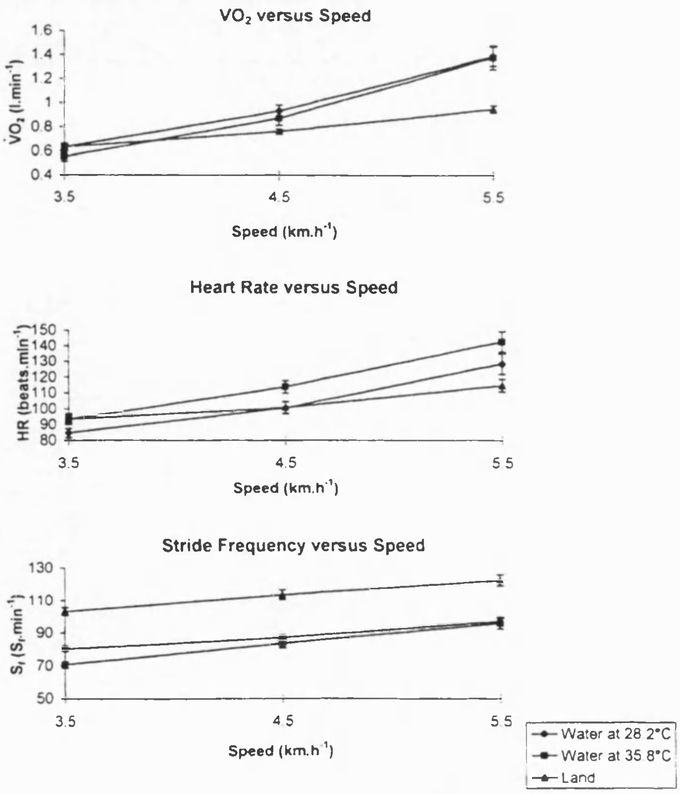


Fig. 1 Oxygen consumption ($\dot{V}O_2$), heart rate (HR) and stride frequency (S_f) versus speed. $\dot{V}O_2$ was significantly higher in water than on land at both 4.5 and 5.5 km · h^{-1} ($P \leq 0.05$). HR was significantly higher in water at 35.8°C compared to water at 28.2°C at all speeds and compared to land walking at both 4.5 and 5.5 km · h^{-1} ($P \leq 0.05$). At all speeds S_f was significantly lower in water than on land ($P \leq 0.001$)

Table 1 Mean (SEM) for ventilation ($\dot{V}_E$: $l \cdot min^{-1}$), respiratory exchange ratio (*R*) ratings of perceived exertion for legs and breathing (*RPE-L* and *RPE-Br*, respectively) and oxygen consumption cost per stride ($\dot{V}O_2/str$: $ml \cdot min^{-1}$). Both $\dot{V}_E$ and *R* increased significantly with speed ($P < 0.001$)

Variable	Speed ($km \cdot h^{-1}$)								
	3.5	4.5	5.5	3.5	4.5	5.5	3.5	4.5	5.5
$\dot{V}_E$	16.03	22.57	34.87	14.81	22.51	36.07	16.3	19.38	23.86
	(0.4)	(0.65)	(1.65)	(0.8)	(1.4)	(2.8)	(1.0)	(0.6)	(0.95)
R	0.84	0.88	0.96	0.84	0.9	0.94	0.83	0.87	0.89
	(0.02)	(0.02)	(0.02)	(0.02)	(0.02)	(0.02)	(0.02)	(0.02)	(0.02)
RPE-L	9.25	11.13*	14.13*	9.25	11.75*	14.13*	8.25	9.88	11.25
	(0.6)	(0.3)	(0.6)	(0.6)	(0.6)	(0.6)	(0.3)	(0.4)	(0.3)
RPE-Br	9.13	10.5	12.25**	9.5	10.88	12.5**	9	9.88	11
	(0.5)	(0.3)	(0.5)	(0.6)	(0.5)	(0.5)	(0.6)	(0.5)	(0.5)
$\dot{V}O_2$/str	7.91***	10.77***	14.43***	7.83***	10.48***	14.39***	6.1	6.73	7.8
	(0.3)	(0.6)	(0.9)	(0.5)	(0.7)	(1)	(0.4)	(0.2)	(0.3)

* RPE for the legs was significantly greater during water exercise than land at both 4.5 and 5.5 $km \cdot h^{-1}$ ($P \leq 0.001$)
** RPE for breathing was significantly greater during water walking than land at 5.5 $km \cdot h^{-1}$ ($P \leq 0.01$)
*** The $\dot{V}O_2$ cost per stride was significantly greater in water than on land at all speeds ($P < 0.05$)

and was not affected by water temperature (see Table 1). The $\dot{V}_E/\dot{V}O_2$ relationship was the same for each of the three conditions.

Figure 1 shows that for all conditions HR increased as speed increased ($P \leq 0.001$). In addition, HR was significantly greater in water at 35.8°C compared to water at 28.2°C at all speeds, and compared to land walking at both 4.5 and 5.5 $km \cdot h^{-1}$ ($P \leq 0.003$). Furthermore, at 3.5 $km \cdot h^{-1}$ HR was significantly lower in water at 28.2°C than on land ($P = 0.007$). The HR-$\dot{V}O_2$ relationship appeared to be linear during water and land treadmill walking (Fig. 2). However, the line is shifted to the right in water at 28.2°C such that for a $\dot{V}O_2$ of 0.9 $l \cdot min^{-1}$ the HR was 99.8 $beats \cdot min^{-1}$ in water at 28.2°C, 113.9 $beats \cdot min^{-1}$ in water at 35.8°C, and 112.4 $beats \cdot min^{-1}$ on land ($P \leq 0.003$).

The RPEs for the legs were similar at 3.5 $km \cdot h^{-1}$, but were significantly higher in water at 4.5 and 5.5 $km \cdot h^{-1}$ (water: 11.44 and 14.13, respectively; land: 9.9 and 11.2, respectively; $P \leq 0.001$). The RPEs for breathing were similar across procedures at 3.5 and 4.5 $km \cdot h^{-1}$. However, at 5.5 $km \cdot h^{-1}$ the exertion of breathing was significantly greater in water than on land (12.4 versus 11; $P = 0.008$). The RPEs for the legs and breathing were not affected by water temperature (see Table 1).

Water immersion per se had no effect on either systolic (SBP) or diastolic blood pressure (DBP) (see Table 2). After exercise in water (at both 28.2°C and 35.8°C) and on land SBP increased significantly ($P = 0.002$). Exercise in water resulted in greater increases in SBP than on land, with the largest rise being observed following exercise in water at 35.8°C ($P \leq 0.03$). DBP did not change after exercise in water at 28.2°C or on land, but was significantly decreased in water at 35.8°C ($P = 0.005$). Water immersion per se did not affect the pulse pressure (PP), but exercise in water resulted in a significantly greater PP than on land [62.75 (4.6) versus 44 (4.3) mmHg: $P \leq 0.04$]. Although non-significant ($P = 0.06$), a greater PP was noted after exercise in water at 35.8°C compared to that in water at 28.2°C.

The S_f increased significantly and linearly with speed ($P = 0.0001$; see Fig. 1). At all speeds S_f in water was 27 strides/min slower than that on land ($P = 0.0001$). In water, S_f was similar at 4.5 and 5.5 $km \cdot h^{-1}$. However, at 3.5 $km \cdot h^{-1}$ subjects walked 9.65 strides/min slower in water at 35.8°C than in water at 28.2°C ($P = 0.001$). The $\dot{V}O_2$ cost per stride at each speed is shown in Table 1, and was significantly greater in water than on land at all speeds ($P \leq 0.005$).

Discussion

$\dot{V}O_2$ and HR increase with speed

$\dot{V}O_2$ and HR increased significantly with increasing speed, but $\dot{V}O_2$ was significantly greater at 4.5 and 5.5 $km \cdot h^{-1}$ in water than on land. At 3.5 $km \cdot h^{-1}$ $\dot{V}O_2$ was similar across the three conditions, suggesting that walking at this speed minimised the drag forces in water. Furthermore, the RPE for legs and breathing was similar at 3.5 $km \cdot h^{-1}$ in water and on land. Resistance to movement in water is, in part, related to the speed of movement, and increases as the square of speed (Clarys 1979). These findings are consistent with those of other studies in which subjects were immersed in chest-deep water and using an underwater treadmill (Gleim and Nicholas 1989; Napoletan and Hicks 1995). At 3.5 $km \cdot h^{-1}$ Napoletan and Hicks reported higher $\dot{V}O_2$ and HR values than we observed ($\dot{V}O_2$: 13 versus 10 $ml \cdot kg \cdot min^{-1}$; HR 98 versus 84.6 $beats \cdot min^{-1}$ in water at 28.2°C). This may be explained on the basis of sample selection; half of their subjects were male with higher mean $\dot{V}O_2$ values. In addition, no details of a familiarisation period were reported, which may suggest that subjects were unfamiliar with the protocol and

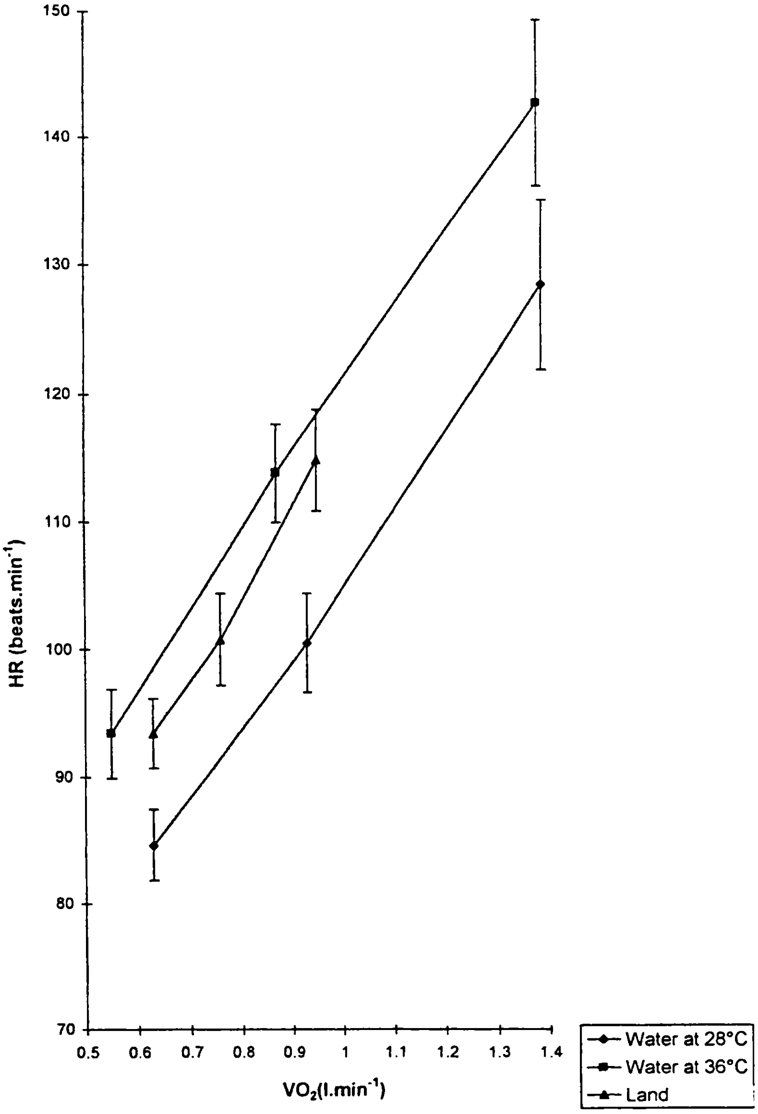


Fig. 2 HR-$\dot{V}O_2$ relationship appears to be linear during water and land treadmill walking and is shifted to the right in water at 28.2°C

therefore had higher HRs. The $\dot{V}O_2$ and HR values for running at 5.5 km · h^{-1} were lower in Napoletan and Hick's study, and this probably reflects the differences between the gait patterns used (i.e. their subjects ran at this speed). Studies in which subjects walk/run across the width of a pool demonstrate higher $\dot{V}O_2$ and HR values than reported here (Evans et al. 1978; Whitley and Schoene 1987). These differences are likely to be related to the method of ambulation and muscle masses activated to maintain the pace; as speed increases, upper limb involvement increases.

Effect of water temperature

At 3.5 km · h^{-1} HR was significantly lower in water at 28.2°C than in water at 35.8°C or on land, and confirms previous findings. During immersion at rest in water at or less than 35°C, HR has been shown to be lower than when on land (Craig and Dvorak 1966; Rennie et al. 1971; Weston et al. 1987). In addition, Nielsen et al. (1984) demonstrated lower HRs during exercise in water at 35°C compared to similar exercise on land. Furthermore, during exercise, at all intensities and in water below 30°C, HRs are lower than when exercising on land or in thermoneutral water (Craig and Dvorak 1968, 1969; McArdle et al. 1976; Moore et al. 1970; Svedenhag and Seger 1992). This probably results from peripheral vasoconstriction in the colder water increasing the total peripheral resistance which augments central blood volume. This will enhance stroke volume and result in a reflex bradycardia. Since specific measures of stroke volume were not included it is not known whether stroke volume was indeed enhanced and whether this altered the workload on the heart. If the increased stroke volume is due to greater filling, as indicated by the authors cited above, this will recruit a larger elastic component and may reduce cardiac work. However, our findings show that HR was similar in water at 28.2°C and on land at both 4.5 and 5.5 km · h^{-1}, and it is possible that

Table 2 Mean (SEM) systolic, diastolic and pulse pressures on land before exercise (*ex*), in water before exercise, and after exercise in water and on land (mmHg)

Condition	Systolic blood pressure			Diastolic blood pressure			Pulse pressure		
	At rest: land	Before ex	After ex	At rest: land	Before ex	After ex	At rest: land	Before ex	After ex
Water at 28.2°C	104.75 (3.8)	101.25 (2.8)	118.75* (3.6)	75.75 (2.6)	73.25 (4.3)	64 (1.2)	29 (2.9)	28 (3.7)	54.75† (3.8)
Water at 35.8°C	103.5 (3.6)	98 (2.9)	124.75*** (3.7)	69.5 (2.2)	66 (2.4)	54*** (2.9)	34 (2.9)	32 (3.9)	70.75† (5.5)
Land	108 (2.9)	108 (2.9)	117* (3.2)	73.75 (3.1)	73.75 (3.1)	73 (4.7)	34.25 (3.4)	34.25 (3.4)	44 (4.3)

* After exercise in water or on land systolic blood pressure increased significantly ($P \leq 0.001$)
** Systolic blood pressure increased significantly more after exercise in water at 35.8°C than in water at 28.2°C or on land ($P < 0.05$)
*** Diastolic blood pressure decreased significantly after exercise in water at 35.8°C ($P < 0.01$)
† Pulse pressure was significantly greater after exercise in water than on land ($P < 0.05$)

this difference is due to gender. In the papers cited above the subjects were male and had a mean body fat of 16% (Craig and Dvorak 1968, 1969; McArdle et al. 1976; Moore et al. 1970). Our subjects were female and had a mean body fat of 27%. Given the relationship between body insulation, exercise intensity and water temperature it is possible that the degree of peripheral vasoconstriction and resulting bradycardia was attenuated in our subjects. Furthermore, the findings from the earlier literature are based on leg work, usually performed via cycle ergometry. Our study utilised walking, and as the intensity increased so did the subjects' use of their arms. It is well known that arm work results in greater increases in HR than does leg work of a similar intensity (Astrand and Rodahl 1986).

HR when walking at 3.5 km · h^{-1} in water at 35.8°C was similar to that on land. At 4.5 and 5.5 km · h^{-1} in water at 35.8°C HR was significantly higher than in water at 28.2°C or on land, despite similar levels of $\dot{V}O_2$ in the former. Few studies have examined the cardiorespiratory response to exercise in warm water. However, the increasing use of hydrotherapy pools, maintained at temperatures of 35–37°C, for cardiovascular conditioning exercise makes it imperative to evaluate metabolic effects. Whilst Kirby et al. (1984) demonstrated that $\dot{V}O_2$ increased with speed during upright walking/running exercise in a hydrotherapy pool with water at 36°C, they omitted to measure HR. Weston et al. (1987) give some valuable insights on the effect of resting water immersion at 37°C. During 15 min of immersion at 37°C Weston et al. noted a tachycardia and an increase in core body temperature of 0.5°C. Thus, our observations of higher HRs after exercise in water at 35.8°C would be consistent with this effect at rest. Weston et al. (1987) speculated that the most important contribution to this tachycardia was the increased rate of sino-atrial node depolarisation that occurs at higher core temperatures. After exercise in water at 35.8°C we noted a 0.65°C rise in oral temperature which is likely to have had a direct effect on sino-atrial discharge, thus increasing HR.

For a given level of $\dot{V}O_2$, HR was lower in water at 28.2°C than on land or in water at 35.8°C. This is important since HR is a parameter that is commonly used to prescribe and monitor exercise intensity. During exercise on land or in water at 35.8°C, HR was similar. Monitoring HR should therefore give a reasonable index of exercise intensity. However, in water at 28.2°C the relationship was different such that for the same HR, overall exercise intensity ($\dot{V}O_2$) would be much higher than in warm water or on land. In his excellent review, Cureton (1997) cautions against using HR values obtained during exercise on land to regulate exercise in water and lists exercise intensity, exercise mode and muscle mass activation, water temperature and depth as the important variables for consideration.

Data on BP responses during water exercise are scarce, and those obtained during resting thermoneutral head-out water immersion are divergent (Epstein 1992). Studies in which land and water cycle ergometry are compared reveal no differences between SBP or DBP responses (Christie et al. 1990; Connelly et al. 1990; Sheldahl et al. 1984). We noted that SBP was significantly greater after exercise in water compared to land, with the greatest rise occurring in water at 35.8°C (by 26.75 mmHg). DBP did not change after exercise on land or in water at 28.2°C, but decreased in water at 35.8°C (by 12 mmHg). The vasodilation resulting from immersion in warm water increases cardiac output and skin blood flow, thereby increasing SBP and reducing DBP. In addition, it is well known that SBP rises more during arm exercise than during leg exercise, and our results may differ from those obtained during cycle ergometry since subjects walked using a reciprocal arm pattern.

Walking speed and S_f

In our study subjects walked at three speeds (3.5, 4.5 and 5.5 km · h^{-1}) in chest-deep water on an underwater treadmill. The diversity of gait patterns, whether walking or jogging at the same speeds, across studies deserves comment. In contrast with our study, that of Evans et al. (1978) showed that subjects maintained a "modified jog or run" at speeds of 2.95, 3.3 and 3.6 km · h^{-1} in waist-deep water. However, that study was conducted in a swimming pool in which subjects were required to traverse from one side of the pool to the other at a given pace. Due to the resistance of the water, which increases relatively with speed, it may have been impossible to maintain the pace without running. Evans et al. omitted to report on the use of arms as a means of propulsion during the faster speeds. Napoletan and Hicks (1995) utilised two speeds on an underwater treadmill in thigh- and chest-deep water. At 3.5 km $\cdot$ h^{-1} subjects walked, and at 5.6 km $\cdot$ h^{-1} subjects ran. They noted that $\dot{V}O_2$ and HR were similar for chest-deep running and dry treadmill running at 5.6 km $\cdot$ h^{-1}. In our pilot studies we found similar results, but subjects had great difficulty in running on a land treadmill at this speed (i.e. 5.6 km $\cdot$ h^{-1}). In addition, the S_f between the two media were significantly different, suggesting that subjects minimised their efforts during water running by using buoyancy to slow the movement, and thus reduced resistance.

Whilst S_f increased linearly with speed in water, it was approximately 27 strides/min less than that on land at all speeds. This is probably a reflection of the greater resistance to movement encountered in water. A lower S_f and higher $\dot{V}O_2$ cost per stride in water has been reported by other authors (Frangolias and Rhodes 1995; Town and Bradley 1991) and attributed to water viscosity and resistance. Frangolias and Rhodes (1995) noted an approximate average difference of 68 strides/min between water and land running, which is much greater than that noted in our study. However, Frangolias and Rhodes utilised a tethered deep-water run with flotation vests, and the non-weight-bearing component may have altered gait biomechanics and hence speed. In addition, Wilder et al. (1993) noted a lower HR at 96 strides/min (92 beats/min) than noted in our study (water at 28.2°C; 97 strides/min, 128.4 beats/min; water at 35.8°C: 95.7 strides/min, 142.6 beats/min). This may be a function of subject fitness and familiarity, since Wilder's subjects were recruited from a current aqua running class, or may be related to the (unreported) water temperature.

Conclusions

The study reported here has shown that walking in chest-deep water at speeds greater than 4 km $\cdot$ h^{-1} requires a greater energy expenditure than that required on a land treadmill. Therefore, to induce the same energy expenditure in water as on land at a speed of 3.5 km $\cdot$ h^{-1} a similar walking speed would need to be adopted. Higher water temperatures augment the HR response to both light and moderate exercise, and therefore caution, in terms of pool temperature and exercise intensity, may be recommended for an older population at possible risk of cardiovascular disease. Despite the limitations of HR as a useful indicator of exercise intensity in water the subjects in this study were able to exercise within the HR ranges accepted by the American College of Sports Medicine as necessary for an aerobic training effect. Thus, people with weight-bearing difficulty due, for example, to injury, arthritis or obesity, could walk on an underwater treadmill to promote cardiovascular conditioning.

Acknowledgements We gratefully acknowledge help from the following: Linda Jefferson, Audrey Ayling, Val Russell and Colin Delpaul, (laboratory assistants), the Physics and Physiotherapy Departments at the Royal United Hospital, Bath, Hazel Gimblett and Shirley Yard (Pulmonary Physiology, Royal United Hospital, Bath), Paul Christie (Bath University) for statistical help, and Heather Parkin (Queen's Medical School, Nottingham University) for support with exercise testing. In addition, we would like to thank Ferno UK for all their support, and the Queen's Medical School for lending us equipment. Jane Hall held a Ferno research scholarship and a South and West R&D research bursary whilst completing this work.

References

Astrand P-O, Rodahl K (1986) Textbook of work physiology, 3rd edn. McGraw-Hill, New York

Borg GAV (1982) Psychophysical basis of perceived exertion. Med Sci Sports Exerc 14:377–381

Christie JL, Sheldahl LM, Tristani FE, Wann LS, Sagar KB, Levandoski G, Ptacin MJ, Sobocinski A, Morris RD (1990) Cardiovascular regulation during head-out water immersion exercise. J Appl Physiol 69:657–664

Clarys JP (1979) Human morphology and hydrodynamics. In: Terauds J, Bedingfield EW (eds) Swimming III. University Park Press, Baltimore, pp 3–41

Connelly TP, Sheldahl LM, Tristani FE, Levandoski SG, Kalkhoff RK, Hoffman MD, Kalbfleisch JH (1990) Effect of increased central blood volume with water immersion on plasma catecholamines during exercise. J Appl Physiol 69:651–656

Craig AB, Dvorak M (1966) Thermal regulation during water immersion. J Appl Physiol 21:1577–1585

Craig AB, Dvorak M (1968) Thermal regulation of man exercising during water immersion. J Appl Physiol 25:28–35

Craig AB, Dvorak M (1969) Comparison of exercise in air and in water of different temperatures. Med Sci Sports 1:124–130

Cureton KJ (1997) Physiologic responses to water exercise. In: Routi RG, Morris DM, Cole AJ (eds) Aquatic rehabilitation. Lippincott, New York, pp 39–56

Epstein M (1992) Renal effects of head-out water immersion in humans: a 15-year update. Physiol Rev 72:563–621

Evans BW, Cureton KJ, Purvis JW (1978) Metabolic and circulatory responses to walking and jogging in water. Res Q 49:442–449

Frangolias DD, Rhodes EC (1995) Maximal and ventilatory threshold responses to treadmill and water immersion running. Med Sci Sports Exerc 27:1007–1013

Gleim GW, Nicholas JA (1989) Metabolic costs and heart rate responses to treadmill walking in water at different depths and temperatures. Am J Sports Med 17:248–252

Hall J, Skevington SM, Maddison PJ, Chapman K (1996) A randomized and controlled trial of hydrotherapy in rheumatoid arthritis. Arthritis Care Res 9:206–215

Kirby RL, Sacamano JT, Balch DE, Kriellaars DJ (1984) Oxygen consumption during exercise in a heated pool. Arch Phys Med Rehabil 65:21–23

Lebrun CM, McKenzie DC, Prior JC, Taunton JE (1995) Effects of menstrual cycle phase on athletic performance. Med Sci Sports Exerc 27:437–444

McArdle WD, Magel JR, Lesmes GR, Pechar GS (1976) Metabolic and cardiovascular adjustment to work in air and water at 18, 25, and 33°C. J Appl Physiol 40:85–90

Moore TO, Barnhauer EM, Seto G et al. (1970) Effect of immersion at different water temperatures on graded exercise performance in man. Aeropsace Med 41:1404–1408
Napoletan JC, Hicks RW (1995) The metabolic effects of underwater treadmill exercise at two depths. APTR 3:9–14
Nielsen B, Rowell LB, Bonde-Petersen F (1984) Cardiovascular responses to heat stress and blood volume displacements during exercise in man. Eur J App Physiol 52:370–374
Rennie DW, diPrampero P, Cerretelli P (1971) Effects of water immersion on cardiac output, heart rate and stroke volume of man at rest and during exercise. Med Sport (Roma) 24:223–228
Sheldahl LM, Wann LS, Clifford PS, Tristani FE, Wolf LG, Kalbfleisch JH (1984) Effect of central hypervolaemia on cardiac performance during exercise. J Appl Physiol 57:1662–1667
Svedenhag J, Seger J (1992) Running on land and in water: comparative exercise physiology. Med Sci Sports Exerc 24:1155–1160
Town GP, Bradley SS (1991) Maximal metabolic responses of deep and shallow water running in trained runners. Med Sci Sports Exerc 23:238–241
Weston CFM, O'Hare JP, Evans JM, Corrall RJM (1987) Haemodynamic changes in man during immersion in water at different temperatures. Clin Sci 73:613–616
Whitley JD, Schoene LL (1987) Comparison of heart rate responses: water walking versus treadmill walking. Phys Ther 67:1501–1504
Wilder RP, Brennan DK, Schotte DE (1993) A standard measure for exercise prescription for aqua running. Am J Sports Med 21:45–48

Physical Therapy Reviews 2001; **6**: 215–29

ACUTE PHYSIOLOGICAL EFFECTS OF EXERCISE IN WATER

J. HALL*, D. BLAKE† and G. GARBUTT‡

**Physiotherapy Dept, Royal United Hospital, Combe Park, Bath, BA1 3NG, UK, †Royal National Hospital for Rheumatic Diseases, Upper Borough Walls, Bath, BA1 1 RL, UK and ‡School of Health Sciences, University of East London, London, E15 4LZ, UK*

ABSTRACT

The acute effects of exercise in water may differ from those on land because of the physical properties of the water. The increased hydrostatic pressure causes a hypervolaemia, which influences the haemodynamic effects of exercise in water. Water resistance and temperature affect the metabolic pathways utilized during exercise. As a result the use of land-based norms to prescribe and monitor water exercise may be unreliable. This review focuses on upright exercise in water, namely cycle ergometry and walking/running.

Oxygen consumption (VO_2) and heart rate are influenced by the depth and temperature of the water, exercise mode and speed. For example, cycle ergometry on land and in water yield similar maximal oxygen uptake (VO_{2max}) responses. However, shallow water running elicits a VO_{2max} which is approximately 10% lower than similar land activity. Deep water running yields a 26% lower VO_{2max} than on land.

Cycle ergometry and walking/running in water have been shown to provide cardiovascular benefits in line with the American College of Sports Medicine guidelines. However a complex interaction exists between the water, exercise and subject variables which will affect the exercise response. Future research should focus on the biomechanical and neuromuscular effects of exercise in water at various depths.

INTRODUCTION

Non-swimming exercise in water is becoming increasingly popular. According to one recent report, 60 000 people in Britain attend aqua-aerobics classes each week.[1] The benefits are believed to be similar to land exercise but without the risk of injury because of the weight-relieving properties of water. However, the physiological effects of water immersion may alter the acute and chronic adaptations to exercise because of the increased hydrostatic pressure. For each 30 cm of water immersion, hydrostatic pressure increases by 22.4 mmHg. In chest-deep water this results in a translocation of approximately 700 ml of fluid from the peripheral circulation into the cardiothoracic compartment.[2] This hypervolaemia has profound implications for cardiovascular and pulmonary haemodynamics.

Other physical properties of water may alter the cardiovascular responses compared to dry land activity. Buoyancy supports the body weight, reducing postural muscle activity and maximal oxygen uptake (VO_{2max}) compared with land.[3] Conversely, resistance to movement in water results from the greater viscosity and drag forces than in air. Resistance increases with velocity, therefore it is possible that energy expenditure could be greater in water. Thus, the interaction between buoyancy and viscosity may effect energy expenditure in water which can be similar to, greater or less than during land activity depending on the manipulation of these variables. Furthermore, water temperature is known to affect the physiological response to exercise. Circulation may be diverted for thermoregulatory purposes to a greater extent than during exercise at similar temperatures on land, because of the greater heat conductivity of water thereby disrupting the cardiovascular response.[4]

This review focuses on the metabolic and cardiovascular responses to acute upright non-swimming exercise in water. Such exercise includes cycle ergometry, walking and running in water at various depths. Shallow water activity implies that walking/running is performed with the feet in contact with the pool bottom and the subject progresses across the width of the pool, walks or runs on an underwater treadmill or walks against the resistance of a swimming flume. During deep water activity the subject is suspended upright, often with the help of a buoyancy vest, in deep water and the feet do not make contact with the pool bottom.

The underlying physiological effects of head-out water immersion (HOWI) persist with the addition of exercise and therefore it is important to be acquainted with some fundamental aspects of immersion physiology before examining differences between various forms of non-swimming exercise.

HEAD-OUT WATER IMMERSION (HOWI)

The hypervolaemia of immersion is attributed to the hydrostatic pressure of the water, which displaces blood from the vascular columns cephalad and alters the balance of Starling forces across capillary membranes. This results in the movement of fluid from intra- and intercellular compartments to the vascular space. Arborelius[2] reported that approximately 700 mls are displaced centrally during upright immersion to the neck. An additional 200 mls are added to the total blood volume via fluid shifts.[5] Yamazaki[6] noted that this haemodilutional effect was maximal after 20–25 min of upright immersion. The extent of the volume expansion is dependent on water depth and posture, upright immersion to the neck providing the greatest hypervolaemia.[7] The volume increase is located in the central compartment, with the heart accepting approximately one third and the lung vasculature the remainder.[3] Central venous pressure increases by 3–15 mmHg and pulmonary arterial pressure by 10 mmHg.[2,9–11] Consequently, cardiorespiratory dynamics are altered at rest and during exercise.

Cardiovascular Effects

The augmentation in heart volume is reflected by increases of 34% and 50% in cardiac output and stroke volume (SV) respectively with significant reduction in heart rate (HR) during thermoneutral (34.5–35°C) HOWI to the suprasternal notch.[10,12,13] The increase in SV is attributed, by Starling's law, to a significant elevation of both ventricular end diastolic and systolic volume.[9] Alterations in HR during resting HOWI are largely dependent on water temperature. In thermoneutral and cool water, HR typically drops by approximately 10–15 beats·min^{-1}. In warm water, Weston *et al.*[13] reported increases of 8 and 34 beats·min^{-1} at 37° and 39°C respectively. The bradycardia of lower water temperatures is probably mediated through cardiac vagal innervation whereas the tachycardia associated with warm water may be related to falls in peripheral resistance and enhanced sino-atrial node depolarization, secondary to increased body temperature. Tachycardia and increased ventricular wall tension are known to increase myocardial oxygen consumption, which may be undesirable in patients with cardiac dysfunction. Hence, the water temperature should be maintained at thermoneutral, and lower depths may be utilized to minimize the degree of volume expansion.

Despite numerous invasive and non-invasive investigations, there remains a lack of unanimity regarding the effect of HOWI on blood pressure (BP). However, given that BP is the primary regulated variable within the cardiovascular system and that the increased cardiac output is reflected by a fall in total peripheral resistance of 31–37%,[7,12,13] it is plausible to speculate that reported changes in BP are due to errors in technique and lack of posture standardization. Indeed, in his review Epstein concludes that BP is probably unaltered during HOWI.[7]

BP is the product of cardiac output and total peripheral resistance. Therefore to enable BP to remain unchanged in the face of increasing cardiac output during thermoneutral HOWI, peripheral resistance reduces by approximately 35%.[13] The increased CO is redistributed to the skin and muscle beds rather than the splanchic[14] or renal circulations.[15] Balldin[16] showed that blood flow increased by approximately 227% during thermoneutral chest-deep water immersion. An increased blood flow would suggest that oxygen transport is enhanced, which may facilitate aerobic pathways. However, the hydrostatic pressure may limit peripheral blood flow, especially to the legs, and this maldistribution may shift cellular respiration towards anaerobic metabolism. Therefore, some of the consequences of HOWI may enhance cardiovascular dynamics and some not.

Respiratory Effects

Thoracic vascular engorgement and elevation of the diaphragm resulting from HOWI decreases lung compliance, thereby altering pulmonary function and increasing the work of breathing. Therefore it is possible that patients with inspiratory muscle weakness may prefer to limit immersion to below the thorax. Vital capacity (VC) is reduced by approximately 10%,[8,17] although fluctuations have been noted to be temperature dependent. Choukroun[18] reported increased VC in water at 40°C. This was associated with a decrease in electromyographic amplitude of the rectus abdominis. The authors suggested that abdominal wall stiffness was reduced at higher temperatures, thus enabling a greater VC. Central vascular engorgement may alter the ventilation–perfusion ratio and affect arterial oxygen concentration (PaO_2). Falls in PaO_2 and increases in alveolar–arterial differences have been reported by a number of authors[19,20] but disputed by Derion[21] and Choukran[22] who found no significant changes.

It is generally accepted that oxygen consumption is not affected by thermoneutral water immersion but increases significantly in water below neutral[18,23] due to shivering thermogenesis. The larger oxygen consumption (VO_2) during cold water immersion combined with an enhanced cardiac output, mediated principally by vasoconstriction, has been shown to increase O_2 extraction by the tissues.[22] Oxygen transport is enhanced above thermoneutral temperatures due to the increased cardiac output resulting from increased hydrostatic pressure and body heating, but O_2 extraction is unchanged as VO_2 remains similar to that in thermoneutral water. Whilst cellular respiration appears unaffected by HOWI, the respiratory requirements and the work of breathing may be greater during water exercise as a result of water resistance and turbulence. Therefore, maximal responses to exercise in water may be attenuated.

Renal Effects

The renal effects of HOWI, secondary to distension of the volume receptors via central volume expansion, have been well documented by Epstein.[7] The increased diuresis starts within the first immersion hour and peaks in the second whilst the natriuresis peaks in the fourth or fifth immersion hour. These events are neurohormonally mediated[10] and are depth and temperature dependent.[24,11] However, the significance of the renal effects of HOWI may not be important given that immersion times for patients undergoing hydrotherapy or athletes training in water rarely exceed 1 h.

Sympathetic Nervous Activity

HOWI has been shown to reduce peripheral venous tone and cause reflex dilatation of the renal afferent arterioles. This is attributed to a generalized suppression of the sympathetic nervous system, required to maintain haemodynamic homeostasis, and has been conclusively demonstrated by Mano.[25] Using microneurographic techniques, Mano showed that muscle-sympathetic nervous activity from the tibial and peroneal nerves was reduced during HOWI. The degree of suppression is related to the extent of central volume expansion. For example, muscle-sympathetic nervous activity was reduced by approximately 24% and 73% during waist- and neck-deep HOWI respectively, compared to standing on land. Furthermore, plasma noradrenaline, a crude measure of sympathetic activity, was significantly reduced within the first hour of thermoneutral immersion.[10,26,27,28] Norsk[27] demonstrated concomitant increases in stroke volume and central venous pressure suggesting that the mechanism was linked to the stimulation of low-pressure baroreceptors by the central hypervolaemia. This was recently confirmed by Gabrielsen[10] who observed an inverse relationship between plasma noradrenaline suppression and water depth.

Thermoregulation

Body temperature regulation is different in water than in air because during immersion heat cannot be lost through evaporation of sweat. Due to the greater heat conductivity of water, heat exchanges are much faster.[29] Core body temperature changes are related to water temperature, speed of movement or exercise intensity and body fat levels.[30] As such, heat may be gained, lost or remain the same. HOWI in thermoneutral water (34.5–35°C) does not alter core body temperature, but after immersion for one hour in water above 36°C, rectal temperature increased and in water below 33°C shivering occurred.[31] Maintaining core body temperature when exercise is added alters the thermoneutral temperature from 17°C to 34°C depending on the intensity of exercise and body fat levels.[32,33] The recommended temperature for exercising in water depends on the purpose of the exercise. Recreational pools are maintained at approximately 28°C whilst therapeutic pools range from 34.5–36°C. The higher water temperatures of hydrotherapy pools is required because the user populations are typically incapacitated and the rehabilitation programmes utilize varying intensities of exercise. Therefore, patients may rapidly lose heat during periods of low levels of exercise intensity and increase core body temperature during intense activity. A balanced exercise programme, alternating low and high levels of exercise intensity, should therefore be adopted to offset the deleterious effects of heat stress.

HOWI AND EXERCISE

Before discussing the metabolic and cardiorespiratory differences between the various forms of non-swimming exercise, it is necessary to consider the likely effects that the addition of dynamic exercise may have on the hypervolaemia of resting immersion. Theoretically, exercise may augment the volume expansion via venoconstriction, muscle and respiratory pump action or reduce it as a consequence of blood redistribution. Certain generalizations may be assumed with regard to the hypervolaemia during exercise in water to the extent that the posture adopted during shallow and deep water running is similar to that during upright cycle ergometry. Invasive studies on cardiac performance and echocardiography during immersed cycle ergometry have shown that the hypervolaemia is maintained but not increased with the addition of exercise.[19,34] For example, Christie[9] reported that right atrial pressure, left ventricular end-diastolic and systolic volumes and left ventricular ejection remained significantly elevated during immersed cycle ergometry compared to land but did not increase with the addition of exercise. This suggests that the system is already operating at maximum volume with the Frank-Starling reserve saturated and contractility unaltered. Bryne *et al.*[35] utilized the CO_2 rebreathing method to evaluate cardiac output during walking exercise in chest-deep water and confirmed that the hypervolaemia of immersion was maintained but not augmented during exercise. Therefore, with a maximum stroke volume prior to exercise in water, increasing VO_2 must be mediated through increasing HR, assuming no alteration of the arteriovenous difference.

Water immersion and exercise have antagonistic effects on fluid shifts. HOWI can cause a haemodilution[6] whereas exercise on land generally results in a relative haemoconcentration.[36] Ertl *et al.*[37] reported a 10.4% plasma volume increase after 20 min of seated HOWI. This haemodilution was partially attenuated (by 64%) following 10 min of immersed cycle ergometry at 38% VO_{2max}. At 62% VO_{2max}, the haemodilution of HOWI was completely attenuated. Thus, immersion-induced increases in plasma volume during resting HOWI are attenuated by exercise and are intensity dependent.

The hypervolaemia induced by HOWI is maintained, but not augmented, with the addition of exercise. The intensity of exercise dictates the magnitude of any changes in renal and fluid shift. Together with water temperature, exercise intensity plays a major role in regulating body temperature. Thus, exercising at a submaximal VO_2 of 0.7l·min^{-1} in 34°C maintained core body temperature but exercising at 0.9l·min^{-1} increased it.[33] However, the physiological costs of exercise in water are not only related to the consequences of increased hydrostatic pressure and temperature but, also, to the effects of buoyancy and viscosity. The interactions of these properties unite to create a complex picture of energy expenditure during exercise.

CARDIORESPIRATORY RESPONSES TO DIFFERENT MODES OF UPRIGHT EXERCISE IN WATER

Cycle Ergometry in Water

Cycle ergometry in water has proved to be a useful method of evaluating physiological responses to exercise in water. Morlock and Dressendorfer[38] described the ease with which a Monark cycle ergometer could be immersed in water and reported that pedal frequency was related to VO_2 by a third-order polynomial. To elicit VO_{2max}, high pedal frequencies (80 rpm) outside the perceived comfortable range (29–40 rpm) were required and this was difficult to maintain for prolonged periods. Shapiro *et al.*[39] addressed this problem by adding fins to either side of the flywheel to increase the drag. Exercise intensity could be increased by the addition of fins without significantly increasing the cycling cadence. The addition of 0–4 fins, with pedalling frequencies in the range of 30 to 40 rpm, elicited a range of VO_2 between 0.5 to 4 l·min^{-1}. Therefore, most studies comparing land and water based cycle ergometry regulate workload by pedal frequency, which determines the oxygen cost.[9,17,26,37,40–42]

Similar levels of VO_2 are elicited during submaximal and maximal cycle ergometry in water and on land.[9,26,37,41,52,43] For a given VO_2, cardiac output (CO) is higher during immersed cycle ergometry than on land, indicating that the central hypervolaemia alters the VO_2–CO relationship. This shows that, despite the increased blood flow, the distribution of which remains uncertain, the exercising muscles do not use the additional O_2 from the augmented CO. An alternative explanation is that arteriovenous differences are lower to compensate for the increased cardiac output, although there appears to be no advantage of this.

Heart rate during water-based cycle ergometry exhibits an intensity dependent effect.[9,26,41,43] Below an exercise intensity of 60–80% VO_{2max}, HR is similar in water and on land. Above this level HR is approximately 10–12 beats·min^{-1} lower during cycle ergometry in water.[9,26,41,43] Given that increases in HR at exercise intensities above 50% of VO_{2max} are primarily dependent on increased sympathetic nervous activity, it is possible that the inhibiting effects of water immersion on sympathetic neural outflow are responsible for the reduced HR during heavy and maximal exercise in water.[25] This is supported by Connelly[26] who reported that, whilst norepinephrine and epinephrine increased exponentially with exercise in water up to 60% VO_{2max}, plasma norepinephrine, an index of sympathetic nervous system activation, was lower in water than on land beyond this intensity. Despite an increased blood flow during immersed cycle ergometry, VO_{2max} was similar between water and land suggesting that O_2 delivery was also similar. Plasma epinephrine, a marker of adrenal medulla activity was also reduced at VO_{2max} only. This suggests that the sympathoadrenal responses to cycle ergometry in water were reduced in intensity dependent manner.

It can be seen therefore, that prescribing exercise intensity in water on the basis of land-attained HR requires caution as the HR–VO_2 relationship is altered during immersed cycle ergometry, such that higher workloads in water are associated with lower HR than on land for a given VO_2. This altered relationship depends, not only on exercise intensity, but also on water temperature. Above water temperatures of 30°C, a lower HR occurs during heavy and maximal exercise only. Below 30°C, HR is reduced at all intensities and is compensated for by a proportionate increase in stroke volume, mediated by peripheral and cutaneous vasoconstriction.[33,44,45] Hence, at lower water temperatures, the effect of temperature outweighs the effect of hydrostatic pressure.

Exercise intensity may be gauged by the respiratory exchange ratio (RER). During high intensity exercise, the RER may rise significantly above 1.0 and may be associated with increasing plasma lactate. Connelly[26] reported that the RER was similar during submaximal and maximal cycle ergometry although plasma lactate was significantly lower in water during maximal exercise only (6.2 and 9 $mmol \cdot l^{-1}$ respectively). This may indicate an increase in muscle blood flow and enhanced aerobic metabolism, thus reduced lactate production, or that clearance rates were increased only during maximum exercise in water. However, plasma epinephrine was also reduced at VO_{2max} and given that epinephrine enhances the glycogenolytic response, a reduced level may have decreased the rate of muscle glycogenolysis with subsequent lowering in plasma lactate.

During cycle ergometry in water, the HR–VO_2 relationship is shifted to the right depending on exercise intensity and water temperature. Therefore, using land-based HR values may underestimate exercise intensity in water. Data on O_2 delivery to working muscles and the response of the sympathetic nervous system during cycle ergometry in water are limited. Further studies examining these variables are required across a range of populations, including the elderly, who appear to have attenuated responses to HOWI.[46-48]

Shallow Water Walking and Running

Shallow water activity may be defined as walking or running in water, usually waist or chest deep, during which the feet make contact with the pool bottom. It is assumed that because a normal heel–toe gait pattern is performed, that this type of activity most closely mimics land locomotion. Two types of shallow water ambulation will be considered in this review, which differ in terms of the frontal resistance encountered. Firstly, walking/running across a pool or within a swimming flume (shallow water walking/running); and secondly, walking on an underwater treadmill. The greater frontal resistance encountered during shallow water walking encourages a forward leaning posture and exaggerated gait pattern (i.e., high knee lift). Therefore comparability of biomechanical stresses between water and land cannot be assumed. To overcome these limitations water treadmills were developed. They provide a more controlled environment for the patient, by individualizing water depth and temperature. This enables evaluation of these variables on the cardiorespiratory demands.

Shallow water walking and running have been compared with land treadmill locomotion and comparable workload has been achieved in a number of ways. Evans[49] measured VO_2 relative to ambulating speed, Town and Bradley[50] compared maximal responses in endurance trained runners, whilst others used speed[57] or perception of exertion[52] as the dependent variable. In these studies, water temperature ranged from 25–31°C, i.e., within the thermoneutral band advocated by Craig and Dvorak[33] and in most cases the subjects have been described as healthy and physically active.

Maximal metabolic responses to shallow water running are lower than on land treadmills. In nine cross-country runners, trained in water running, Town and Bradley[50] reported that VO_{2max} and HR_{max} in waist-deep water was approximately 90% of that on the land treadmill. The respiratory exchange ratio (RER) exceeded 1.0 and was similar to land treadmill running. Plasma lactate was 18.7% lower during shallow water running (6.5 and 8 $mmol \cdot l^{-1}$ respectively). It is likely that resistance to movement in water hampered the runners' ability to generate the limb speed required for maximal effort, hence the differences between shallow water and land treadmill running at maximum effort. A slower limb speed implies recruitment of aerobic slow twitch fibres, which may account for the lower plasma lactate in water together with the lower VO_{2max}. These data were collected from young fit subjects and it is likely that sedentary and older subjects would reach VO_{2max} in water more quickly than on land. Furthermore, the difference in VO_{2max} between water and land might be greater, especially in older subjects with relative muscle weakness who may be unable to overcome the resistance of the water as speed increased and who may fatigue more quickly.

As speed increases during shallow water locomotion, VO_2 and HR show a near linear rise.[49,50,52] Two studies have reported that the HR–VO_2 relationship is linear and comparable to land treadmill work, implying that metabolic intensities may be accurately prescribed from land-based treadmill heart rates.[49,52]

The increased metabolic demands of submaximal shallow water running are evidenced in the slower speeds employed for a given VO_2. Stride frequency is significantly lower during shallow water walking and running.[49,51,52] Evans[49] reported that speeds of 2.5–3.6 $km \cdot h^{-1}$ in water related to 5–13.4 $km \cdot h^{-1}$ on land at matched levels of VO_2. These findings were confirmed by Yu *et al.*[52] who reported a stride frequency approximately 30% slower in water. Therefore, for a given speed, VO_2 is greater in water than on land, and in most instances the same has been found to be true for HR responses. These results may be explained on the basis of the greater resistance to movement in water and the formation of drag forces impeding forward movement of the subject. Furthermore, it is apparent that the resistance to movement has a greater effect on energy expenditure than the reduced body weight associated with buoyancy following immersion to the waist.[53] The resistance to movement may also be responsible for the disparity between perceptual effort and physiological cost in water. Yu *et al.*[52] reported that, for nine untrained female subjects, a given VO_2 yielded significantly higher ratings of perceived exertion (RPE). Relatively few studies have compared shallow water walking and running to land treadmill activity. Extending the scope of study to include haemodynamic, respiratory and endocrine measures would help hydrotherapists and coaches to understand and manipulate the physiological responses occurring during this shallow water locomotion.

Shallow water running prevents attainment of maximal physiological responses observed on the land treadmill but submaximal work provides a sufficient cardiovascular stimulus to meet currently accepted goals for cardiorespiratory fitness development. The resistance to movement slows limb speed as evidenced by reduced cadence during shallow water activity. Since resistance increases as the square of velocity, a slight increase in walking speed will demand greater muscle force to overcome it.[54] Elderly or weak patients may have difficulty activating muscle sufficiently to walk at speeds required for a cardiovascular training effect. They will, however, strengthen muscles involved in shallow water gait but future research should evaluate the potential of elderly and different patient populations to improve cardiovascular fitness through shallow water walking.

Water Treadmill Walking and Running

Because shallow water running is performed in a swimming pool, water depth and temperature are predetermined. The advantage of water treadmill walking/running, when using a bespoke machine, is that alteration of water depth and temperature are easily accomplished. Therefore, it is a valuable research tool, especially when investigating the complex interaction between buoyancy and resistance.

Maximal responses

Maximal responses to water treadmill activity have not been systematically studied. However, Gleim and Nicholas[55] reported that thigh-deep, treadmill water running at 9.6 $km \cdot h^{-1}$ elicited a VO_2 of 50 $ml \cdot kg \cdot min^{-1}$ and HR values of 187 $beats \cdot min^{-1}$ in 6 men and 5 women who trained regularly. These compare closely to typical maximal values for untrained men and women, and suggest that water treadmill running at this depth requires an energy expenditure close to maximal. Maintaining maximal speed, but increasing the water depth to waist height, reduces the metabolic demands to that seen on a land treadmill. Increasing the water depth alters the interaction between water resistance and buoyancy, such that the increased resistance slows movement and the buoyancy supports the body through a prolonged flight phase, thereby reducing energy demand. Therefore, cardiovascular training on a water treadmill must take into account the effects of water depth on energy expenditure.

Submaximal responses

Studies comparing water to land treadmill walking/running, have shown that differences in submaximal VO_2, HR and RPE are affected, in part, by water depth, the speed of movement and whether the

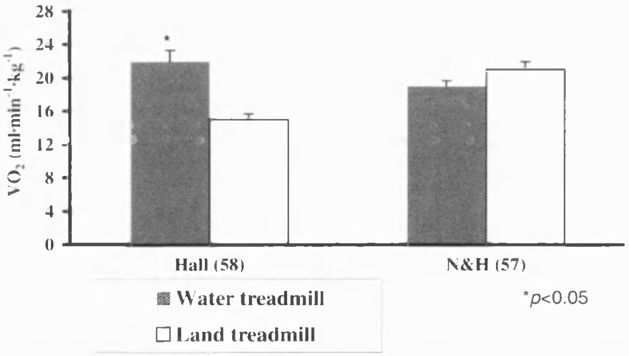


Fig. 1. Treadmill walking in water at 5.5 km·h^{-1} elicits a higher VO_2 ($p < 0.05$) than on a land treadmill (Hall *et al.*),[58] whilst running at 5.5 km·h^{-1} elicits similar values in water and on land (Napoletan and Hicks).[57] *Modified from Hall J, Macdonald IA, Maddison PJ and O'Hare JP, 1998 and Napoletan and Hicks, 1995. Used with permission from* European Journal of Applied Physiology *(Springer-Verlag GmbH&Co) and* Aquatic Physical Therapy Report *respectively*

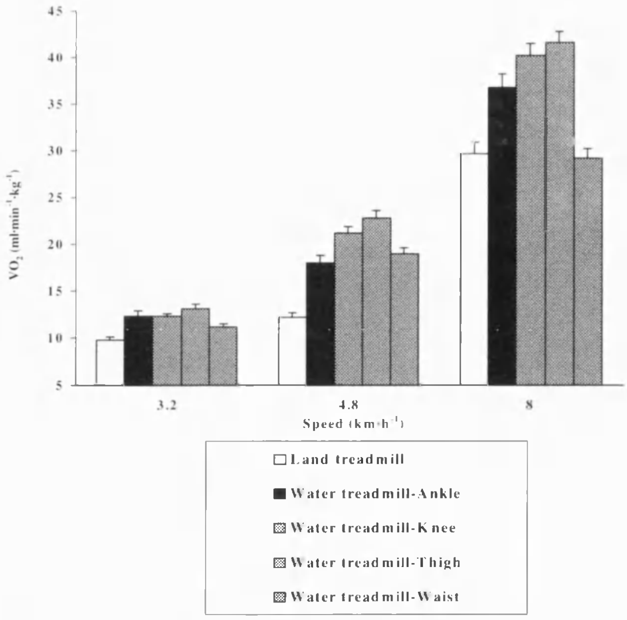


Fig. 2. VO_2 (ml·min^{-1}·kg^{-1}) is affected by immersion depth and running speed (mean and SE). (Adapted from Gleim and Nicholas.[55] Used with permission from *American Journal of Sports Medicine*)

subject is walking or running. VO_2 and HR increase linearly with speed when walking only on a water treadmill.[35,56,57] At slow walking speeds (<3.2 km·h^{-1}) in waist- or chest-deep water, VO_2 and HR[35] are similar to a land treadmill, suggesting that the resistance to movement at this speed is minimal. As speed of walking increases above approximately 3.5 km·h^{-1}, VO_2 and HR become significantly greater in chest-deep water than on a LT.[35,56,57] Increased electromyographic activity of the hip extensors during water treadmill walking confirms that water resistance becomes a critical factor as walking speed increases.[54] However, if the mode of ambulation changes from walking to running in chest-deep water, energy expenditure may be reduced because running encourages a prolonged flight phase. Running at this depth enables the effects of buoyancy to dominate and subjects use the lengthy flight phase to float momentarily whilst the treadmill belt passes below. In support of this, Hall *et al.*[58] reported that walking at 5.5 km·h^{-1} increases energy expenditure compared to land treadmill, whereas Napoletan and Hicks[57] showed that running a this speed decreases VO_2 (Fig. 1).

Water depth affects energy expenditure with depths below the waist requiring greater metabolic demands than higher depths. At 4.5 km.h^{-1} and above, VO_2 and HR were greater for thigh and knee depth than for waist and ankle.[55] Furthermore, at 8.0 km·h^{-1}, ankle-depth water running demanded higher energy expenditure than waist-deep water (Figs 2 and 3). Napoletan and Hicks[57] reported similar results between chest- and thigh-deep water at 3.5 and 5.5 km·h^{-1}. These results reflect the complex interaction between buoyancy and water resistance; at water depths above the waist the effects of buoyancy dominate, especially when running, and at depths below the thigh water resistance impedes movement.

The HR–VO_2 relationship during incremental water treadmill walking/running in waist-deep water at 36°C has been considered in two studies. Hall *et al.*[58] reported no differences in the HR–VO_2 relationship in water at 36°C but Gleim and Nicholas[55] demonstrated higher HR for a given VO_2 compared to a LT. Although body temperature was not measured in Gleim and Nicholas' study,[55] the results are consistent with Weston[13] who speculated that increased core body temperature might increase sino-atrial discharge. In addition to water temperature, exercise intensity is of major importance in thermoregulation during water immersion. Gleim and Nicholas[55] noted that the relationship between HR and VO_2 was most apparent at higher exercise intensities ($VO_2 = 30$ ml·min^{-1}·kg^{-1}) and may, as a consequence, not have been observed in the Hall *et al.* study[58] ($VO_2 = 14$ ml·min^{-1}·kg^{-1}). Therefore, notwithstanding the caveat of low exercise intensities, utilizing land-based HR to predict intensity may overestimate metabolic demand in water at 36°C. The HR–VO_2 relationship has also been considered during water treadmill walking/running in water temperatures at and below 30°C. At low exercise intensities, Hall *et al.*[58] observed significantly lower HR for a given VO_2 in chest-deep water at 28°C compared to land. Whilst Gleim and Nicholas[55] reported higher HR for a given VO_2 in waist-deep water at 30°C, this was most apparent above a VO_2 of 25 ml·kg^{-1}·min^{-1}.

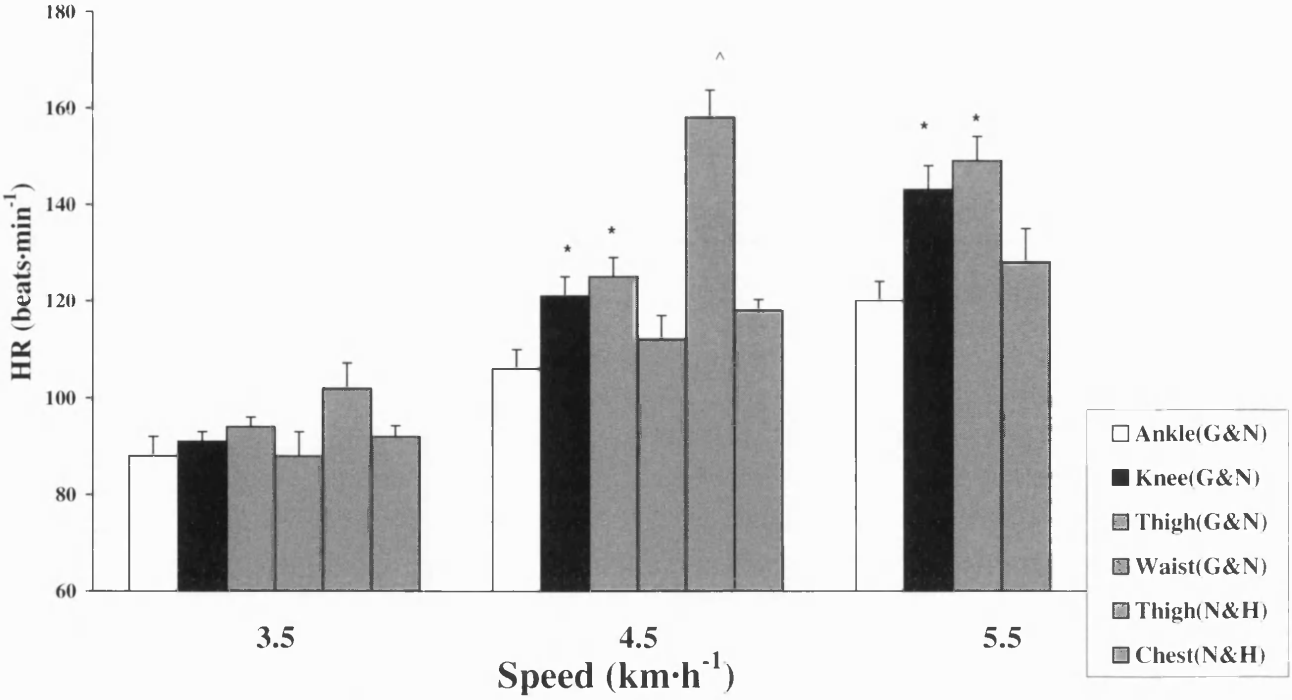


Fig. 3. Water depth affects the HR response to UWT walking/running (mean and SE). Adapted from Gleim and Nicholas[55] and Napoletan and Hicks (N&H).[57] Used with permission. * UWT walking or running at speeds of or greater than 4.5km·h^{-1} in knee- or thigh-deep water elicited higher increases in HR than other water depths (Gleim and Nicholas).[55] ^ UWT walking at 4.5km·h-1·h^{-1} in thigh-deep water elicited a higher HR response than walking in chest-deep water (Napoletan and Hicks[57])

The disaparity between studies probably reflects not only differences in exercise intensity, but water temperature and immersion depth. The uncertainty of prescribing and monitoring water exercise from land-based HR–VO_2 relationships is again highlighted.

Ratings of perceived exertion are significantly greater during water treadmill walking than land treadmill walking for the same speed.[35,57,58] Additionally, walking or running in water at thigh depth produces greater RPE scores than similar activity in chest-deep water.[35] These results mirror those for VO_2 and reflect the enhanced buoyancy and prolonged flight phase in the deeper water. Despite the greater perception of effort in water, the speed of movement is slower, reflecting the increased resistance.[55,58] Hall *et al.*[58] reported that stride frequency increased almost linearly whilst walking on a water treadmill, but was approximately 27 strides·min^{-1} less than on a land treadmill, at speeds between 3.5 and 5.5 km·h^{-1}. These findings are similar to those seen during shallow water activity and are supported by the work of Nakazawa *et al.*[54] who observed a longer stance time during water walking in waist-deep water. Slower limb speed also seems to be a feature of water treadmill running in thigh-deep water, but whether it is of the same magnitude as waist depth is questionable, given the finding that stance time increases with depth.[54] Gleim and Nicholas[55] noted that speed was less than on land for a given VO_2. However, the speed–VO_2 relationship was similar to a land treadmill when running in waist-deep water suggesting that the effects of buoyancy dominated. Given the findings that stride frequency was lower[58] and that buoyancy allows momentary floating as the treadmill belt passes underneath the subject, a more accurate account of energy expenditure may be seen by replacing stride frequency with treadmill belt speed as the dependent variable.

Depending on the speed, mode of locomotion, water depth and temperature, VO_2 and HR during water treadmill walking and running may be higher than, or similar to, land treadmill activity. The differences are associated with the interplay between buoyancy and viscosity, such that at low water depths water resistance dominates resulting in increased energy expenditure and at depths above waist level buoyancy enhances a prolonged flight phase with subsequent reduction in metabolic demand. With the addition of water temperature, the HR–VO_2 relationship becomes a more unreliable indicator for prescribing exercise intensity. Therefore, when using a water treadmill for cardiovascular training consideration must be given to the interaction of all these variables to ensure an appropriate level of energy expenditure. Maximal responses to water treadmill running have not been systematically examined. A comparison with shallow water activity would show whether the greater frontal resistance and altered postural adaptations, actually mediate energy expenditure. Similarly, whilst it is thought that the gait of water treadmill running is closer to that of land running than shallow water or deep water running, biomechanical analysis would clarify this assumption, especially as the joint and muscle actions of deep water running have been shown to differ considerably from land treadmill running.[59]

Deep Water Running (DWR)

Deep water running (DWR) is a non-weight-bearing activity, performed in the deep end of a pool, in which the arms and legs simulate the running motion. The body is upright and the head is held out of the water usually with the aid of a buoyancy device. Sometimes, however, training allows subjects to DWR without such an aid. DWR has been advocated as a training aid for athletes.[50,56,60–67] The impact-free environment is considered to have the potential to reduce the incidence of injury and allows training to continue during injury rehabilitation.[68] Despite the lack of biomechanical specificity, it has been assumed that benefits from DWR will enhance running performance on land.[59]

Maximal Responses

A number of studies have reported maximal responses to DWR.[50,60–62,64,66,69,70–73] During DWR, VO_{2max} is approximately 26% lower than that achieved on a land treadmill and maximum HR is about 14% lower. Despite these differences, RPE values are the same at maximal effort suggesting a disparity between perceptual effort and metabolic response. The inability to attain land-based VO_{2max} values during DWR is attributed to the buoyancy of the water and altered gait with subsequent recruitment pattern differences. It has been suggested that muscle activity during DWR may be less because the antigravity muscles are not required to support the runner's body mass and there is no push-off phase during the gait cycle.[50] Thus, WR becomes an open kinetic chain.[59] Furthermore, reliance on the relatively smaller upper body musculature to aid DWR would result in lower maximal VO_2 values. In waist-deep water, in which the feet are in contact with the pool bottom, VO_{2max} was 90% of that on the land treadmill, during DWR it was only 80%. Dowzer *et al.*[74] demonstrated that spinal shrinkage is significantly less during DWR than SWR or land treadmill, suggesting that lower absolute VO_2 could be associated with the reduced biomechanical load during the take-off and foot strike. Some data also suggest that familiarity with DWR is a contributory factor.[75] Michaud *et al.*[76] demonstrated that the principles of training specificity apply to DWR. After an 8–week DWR programme, VO_{2max} was increased by 6% of that on a LT. This gain is comparable to other forms of aerobic exercise of similar duration and suggests that muscle recruitment patterns in DWR are different from land treadmill running. This is supported by Frangolias and Rhodes[75] who reported that untrained DWR runners achieved 84% of their land-based VO_{2max} whereas trained DWR runners achieved 93%. These authors also showed that DWR familiarity was related to VO_{2max} performance and that the more familiar a runner is with DWR, the smaller the difference between water and land maximal values.

At VO_{2max}, ventilation is similar between DWR and LT running,[60,64,66] although two studies reported significantly lower values in water.[161,73] Similar levels of ventilation during maximal exercise in water suggest that the increase in intra-thoracic blood volume and chest compression from the hydrostatic pressure, which reduces lung capacities and compliance during water immersion, does not impede ventilation during water exercise. Despite the differences between exercise modes, it is noteworthy that Sheldahl *et al.*[41] noted greater breathing frequency and lower tidal volume during cycle ergometry in water than on land. They suggested that this might be a compensatory mechanism to overcome the reduced lung compliance. Future studies on DWR should monitor breathing frequency to clarify this.

Normally, on land treadmill running at VO_{2max} the respiratory exchange ratio (RER) is greater than 1.0. During deep water running, the RER is similar[50,60,61,70,73] or significantly less than land treadmill running.[64,66] Increases in the RER may be related to the buffering of H^+ ions associated with lactate accumulation in the blood and therefore it might be expected that lactate results match those of RER. Fig. 4 shows data from three studies in which blood lactate was measured immediately after exhaustion. Similar,[64] lower[50] and significantly higher[66,70] post-exercise lactates have been noted after DWR compared to land treadmill running. Frangolias and Rhodes[64] suggested that DWR competence might explain the discrepancies. Subjects unfamiliar with DWR exhibited deterioration in their running style during a VO_{2max} test, with increased use of their upper limbs[75]. Differences in these muscle recruitment patterns may account for the lack of consensus. Clearly, future studies must define the subject characteristics more precisely than previous research. Whilst familiarity suggests that lactate responses are similar during maximal DWR and land treadmill running, the buoyancy mediated alteration in eccentric and concentric

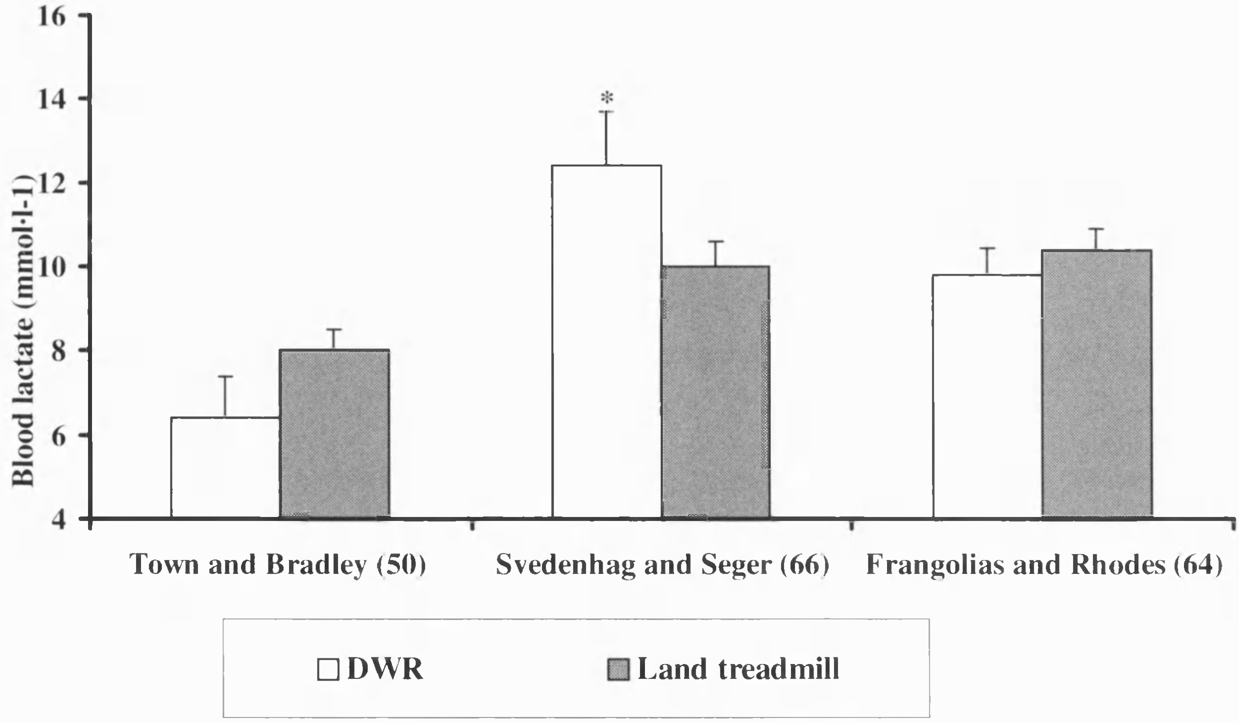


Fig. 4. Mean (and SE) post-exercise blood lactate (mmol·l^{-1}) immediately after exhaustion from DWR and LT. *DWR blood lactate post-exercise was significantly higher than on a LT

contraction during water running, may also affect metabolism. The larger concentric phase during DWR and the longer contraction times (evidenced by a slower cadence) may result in rhythmic ischaemia with consequent reduced oxygen delivery and greater recruitment of type II muscle fibres, which favours lactate production. Therefore, future research should include EMG analysis to establish temporal patterns of gait characteristics, as well as better sample selection.

Metabolic differences between land and DWR have been attributed to differences in running gait as a result of greater resistance to movement in water as well as the lack of foot contact and the hypervolaemia of water immersion. Water viscosity affects stride frequency, which has been found to be significantly lower during DWR than land treadmill running. Frangolias and Rhodes[64] reported that cadence was 68 strides·min slower during DWR compared to land treadmill running at VO_{2max}. Furthermore, Town and Bradley[50] noted that DWR elicited a slower stride rate than SW running (84 versus 108 strides·min^{-1}) at maximal effort. This suggests that increasing immersion depth increases resistance to movement. However, running with the arms above the surface of the water and encountering foot contact, as in SWR, may facilitate gait patterns more akin to land treadmill.

Submaximal DWR

Findings relating to physiological responses to submaximal DWR are conflicting and may be due to study design, and, in particular, the way in which submaximal work intensity has been matched between land treadmill and DWR. Some authors compared self selected pace[56,65,71,77] or relative VO_2[62,66] or cadence.[69,78] Additionally, the aerobic fitness of the subject and the use of a buoyancy aid may affect responses. Studies in which subjects self-select the pace showed that VO_2 is either significantly lower during DWR[56,65] or the same as on land.[65,77] Gehring *et al.*[65] reported that the VO_2 response is altered during DWR as a function of subjects' endurance status. Competitive runners (mean $VO_{2max} = 56.7$ ml·kg·min^{-1}) showed no differences in VO_2 between DWR, with and without a buoyancy aid, and land treadmill. However, recreational runners (mean $VO_{2max} = 47.7$ ml·kg·min^{-1}) had a significantly lower VO_2 in water than on land. Furthermore, DWR with a buoyancy aid yielded a 17% lower VO_2 than DWR without an aid. Gehring *et al.*[65] suggested that the differences between competitive and recreational runners may be related to the level of competitiveness and motivation.

The HR–VO_2 relationship during submaximal DWR is, in some cases, similar[62,65,67,72] or lower, by

10–17 beats·min^{-1}, than land treadmill exercise.[66,77] Michaud *et al.*[72] speculated that thermoregulatory mechanisms may have affected the HR responses between studies and compared the water temperature used in their study (30°C) to the lower temperature (25°C) used by Svedenhag and Seger.[66] At 25°C, especially in subjects with low percentage of body fat, augmentation of preload via vasoconstriction will predispose to bradycardia. However, Yamaji *et al.*[67] reported considerable inter-subject variability, with some subjects showing similar, and some higher HR for a given VO_2. The differences were attributed to the skill of the athlete in performing DWR. Those subjects trained in DWR tended to have lower HR whilst those who relied on extensive use of the arms to keep afloat had higher HR. Given that arm exercise is associated with a higher HR than that observed during leg exercise, this explanation for the divergent results between studies is appealing. Therefore, the present data suggest that prescription of exercise intensity for DWR on the basis of land-based HR values is unreliable, because it may underestimate (especially if water temperatures are low) or underestimate if subjects are untrained in the technique. Adjustment, either higher or lower is required depending on the skill of the subject. Future studies would benefit from taking subject skill at DWR into account.

During submaximal exercise ($VO_2 = 3$ l·min^{-1}), Svedenhag and Seger[66] noted blood lactate was significantly greater in water than on land (4.57 versus 1.47 mmol·l^{-1}). This was confirmed by Michaud *et al.*[72] (5.8 versus 1.6 mmol·l^{-1}) and DeMaere and Ruby[62] who showed that substrate utilization, calculated from RER was different during DWR at 60 and 80% VO_{2max}. Fat oxidation was significantly reduced and carbohydrate oxidation significantly increased during DWR. A significantly increased RER[62,66,69,72] and blood lactate during submaximal DWR suggests a higher anaerobic metabolism than experienced during comparable relative VO_2 on LT work. Svedenhag and Seger[66] speculated that this might be a result of lowered perfusion pressure in the legs with a consequent decrease in total muscle blood flow, compelling type II fibre activation with resultant anaerobiosis. Lack of familiarity with DWR and resulting altered muscle activation patterns may have contributed to the higher anaerobic metabolism. This is confirmed by Michaud *et al.*[72] who reported greater local fatigue in the arms and shoulders of their subjects. Furthermore, they observed that the upper limbs were used more during DWR than on land. Therefore, increased reliance on less trained muscles may account for the differences in substrate utilization between DWR and LT running. Further confirmation of substrate utilization during submaximal DWR using direct methods of measurement will clarify differences between land and water. This is important for weight loss programmes that are designed to utilize fat as the preferred fuel. If lack of skill in DWR predisposes to carbohydrate utilization, a longer training period with appropriate instruction may be required before fat becomes the favoured fuel.

RPE is dependent on the subjects' aerobic fitness and the presence of a buoyancy aid.[65] During DWR, recreational runners wearing a buoyancy aid, reported similar RPE values to land treadmill activity. However, running without a buoyancy aid required significantly greater effort than land treadmill or DWR whilst wearing a buoyancy aid (RPE = 14.2, 12 and 11.5 respectively). These findings follow changes in the VO_2 values. It has been suggested that subject familiarity with DWR may affect perception of effort. DeMaere and Ruby[62] reported similar RPE values between land and water running in subjects who incorporated DWR into their training programmes. Others showed RPE to be significantly higher in competitive runners for whom DWR was a novel experience.[66,76] However, Gehring *et al.*[65] showed no differences in RPE in competitive runners who had never participated in DWR prior to the study, challenging the theory that novice DWRs lack water confidence and movement pattern familiarity.

DWR is associated with lower maximal VO_2, HR and stride frequency but similar RPE values to land treadmill running. The reason for this is the altered biomechanical load resulting from water buoyancy, viscosity and the absence of a ground reaction force. The VO_2 response is altered by subjects' endurance-trained status and familiarity with DWR, and divergent results may be explained due to sample heterogeneity. Future studies must include a comprehensive description of subjects' training status and utilize samples, controlled for sex, endurance ability, level of body fat and DWR competence. The HR–VO_2 relationship is different during DWR, making it difficult to prescribe exercise intensity accurately for DWR on the basis of land HR values. Therefore new studies need to be completed, which will develop water specific HR–VO_2 norms under a variety of subject characteristics and water conditions (i.e., water temperature, depth).

CONCLUSION

This review has focused on the acute metabolic effects of upright exercise in water. Differences between water and land exercise, and the various forms of water exercise, may be viewed as a consequence of altered movement mechanics secondary to the inherent properties of water. VO_{2max} is achieved during immersed cycle ergometry but not during shallow water activity or DWR, implying that resistance to movement is greater in the latter exercise modes. The drag forces are likely to be smaller during pedalling than in running because of the smaller range of movement. Additionally cycle ergometry remains a non-weight bearing activity whether in or out of water and as such it is not affected by buoyancy in the same way as running. It has been suggested that, maximal effort is impeded by the water resistance making it difficult to move long levers to the required speed, hence the cadence is slower and VO_{2max} is not achieved during immersed walking/running activities.[50,56] Differences in the ability to generate VO_{2max} and HR_{max} between shallow water running and DWR may be related to altered muscle recruitment patterns due to the lack of a push-off phase during the gait cycle, the use of the immersed arms, as well as subject familiarity. The extent of the present data suggests that shallow water running provides the most metabolically challenging environment and is closest, biomechanically to land treadmill running. However, maximal responses to water treadmill exercise, at various depths have yet to be fully determined and may offer the best alternative to land-based running.

The bradycardia during moderate and high intensity, immersed, cycle ergometry is attributed to increased hydrostatic pressure causing an attenuation of the sympathoadrenal response via a hypervolaemia mediated stimulation of baroreceptor activity. The sympathoadrenal responses to walking and running exercise in water await investigation, although slower limb speeds with subsequent lower VO_{2max} are likely to account for the inability to achieve land-based HR_{max} values. Additionally, the enhanced immersion induced preload, resulting in greater SV and lower HR, has been proposed to explain lower HR_{max}. Why this occurs only at maximum intensity is unclear. Submaximal HR responses, during shallow water running generally appear to closely match VO_2 responses, whereas the bradycardia seen during immersed cycle ergometry appears above 60% VO_{2max}. This may be related to the addition of active arm use during running, which is known to produce a higher HR for a given VO_2.

Both maximal cycle ergometry and shallow water running have been associated with a lower plasma lactate compared to dry land activity. In the former, this is substantiated by a corresponding decrease in epinephrine release, the latter with a reduction in VO_{2max} and cadence. Slower limb speeds in water may fail to recruit fast glycolytic fibres and contribute to the reduced plasma lactate seen during shallow water activity. However, slow cadence implies longer contraction times, which may reduce muscle blood flow and enhance anaerobiosis. Establishing lactate values at various submaximal intensities will provide a clearer picture of the metabolic pathways used in shallow water running. Furthermore, measuring the sympathoadrenal response during shallow water running will clarify the role of epinephrine versus muscle blood flow in the lactate response. Data on lactate responses during water treadmill walking/running and the varying effects of water depth and temperature await investigation. Whilst the lactate response for a given submaximal exercise intensity seems consistent, the findings for maximal DWR provoke controversy. The disagreement between studies may be resolved with careful use of homogenous samples in respect of cardiorespiratory fitness, age, and familiarity. Plasma lactate is higher for a given VO_2 during submaximal DWR suggesting that this activity is fuelled through anaerobic metabolism, perhaps because of increased reliance on less trained upper body musculature or due to a lowered perfusion pressure in the legs resulting in a decrease in muscle blood flow. An additional explanation is related to subject skill and familiarity with DWR. Future studies which take this into account will help to clarify the maximal lactate response during DWR.

Exercise intensity is commonly prescribed from the relationship of HR values, RPE or plasma lactate relative to VO_2 during land-based activity. Applying this formula to water exercise would depend on a similar relationship in water being demonstrated. However, the similarity of relationships differs between exercise modes. During cycle ergometry the HR–VO_2 relationship exhibits an intensity dependent effect and data from shallow water walking/running and DWR studies show that HR may be similar, lower or higher for a given VO_2. As the differences depend on a myriad of factors including water temperature and depth, speed and type of ambulation, skill and fitness level using land-derived values may over or underestimate the metabolic demands. Because of these difficulties, Wilder *et al.*[79] proposed that cadence provides a more accurate measure for DWR. Whether a similar relationship operates for shallow water activity remains to be investigated.

Despite the controversial results of the RPE–VO_2 relationship during DWR, it is generally accepted that basing exercise intensity on this association may overestimate the metabolic challenge. The higher RPE for a given VO_2 during shallow water activity suggests a similar limitation to the use of this relationship to estimate metabolic demand. The reduced plasma lactate observed during immersed cycle ergometry and shallow water activity for a given VO_2 implies that exercise prescriptions based on this variable would result in a less vigorous aerobic session. During DWR, plasma lactate appears higher in water than on land and therefore, use of this variable would overestimate the required exercise intensity. However, lactate responses during DWR, especially at maximal intensity lack consensus and further research with due regard to the confounding influences identified in this review will be valuable.

Differences between land and water exercise and between the various forms of water exercise are attributed to the physical properties of the water, namely buoyancy, viscosity, hydrostatic pressure and temperature. The data presented here on the acute effects of upright water exercise, show that a cardiovascular training stimulus may occur as a result of water-based programme. This is confirmed by studies on the chronic effects of water training which show that improvement and maintenance of cardiorespiratory fitness is feasible.[80] That the environment is a safe alternative for rehabilitation has also been documented.[68] However, the majority of studies on the acute effects of upright water exercise have concentrated on young healthy subjects and caution is required in the extrapolation of such data to an older and/or ill population. Given the recent findings of differences between young and old subjects during HOWI, it becomes more urgent to investigate the responses of older people to water exercise, especially as this population may uniquely benefit from the load reducing properties of water.[34,46–48] The biomechanical differences between water and land-based walking/running await systematic and comprehensive analysis and should include normal subjects and those with pathology. Upright exercise in water is a useful adjunct for fitness training and rehabilitation for a wide section of the population, however further research, especially into the impact of water programmes on dry land functional activity and the neuromuscular effects, including the influences of age, fitness and familiarity are merited.

REFERENCES

1 Jenner G. In at the deep end. *Style* 1998; February 22:36–37
2 Arborelius M, Balldin U, Lilja B and Lundgren C. Haemodynamic changes in man during immersion with the head above the water. *Aerospace Med* 1972; **43**:592–98
3 Sugajimo Y, Mitarai G, Koeda M and Moritani T. Characteristic changes in motor unit activity in hip joint flexor muscles during voluntary isometric contraction during water immersion. *J Electromyogr Kinesiol* 1996; **6**:83–95
4 Becker BE. Aquatic physics. In : Ruoti RG, Morris DM and Cole AJ (eds) *Aquatic Rehabilitation.* New York: Lippincott, 1997:15–23
5 Khosla SS and Dubois AB. Osmoregulation and interstitial fluid pressure changes in humans during water immersion. *J Appl Physiol* 1981; **51**:686–92
6 Yamazaki F, Endo Y, Torii R, Sagawa S and Shiraki K. Continuous monitoring of change in hemodilution during water immersion in humans: Effect of water temperature. *Aviat Space Environ Med* 2000; **71**:632–39
7 Epstein M. Renal effects of head-out water immersion in humans: a 15-year update. *Physiol Rev* 1992; **72**:563–621
8 Risch WD, Koubenec H-J, Beckmann U, Lange S and Gauer OH. The effect of graded immersion on heart volume, central venous pressure, pulmonary blood distribution, and heart rate in man. *Pflugers Arch* 1978; **374**:115–18
9 Christie JL, Sheldahl LM, Tristani FE, Wann LS, Sagar KB, Levandoski SG, Ptacin MJ, Sobocinski KA and Morris RD. Cardiovascular regulation during head-out water immersion exercise. *Journal of Applied Physiology* 1990; **69**:657–64
10 Gabrielsen A, Videbaek R, Johansen LB, Warberg J, Christensen NJ, Pump B and Norsk P. Forearm vascular and neuroendocrine responses to graded water immersion in humans. *Acta Physiol Scand* 2000; **169**:87–94
11 Norsk P, Bonde-Petersen F and Warberg J. Arginine vasopressin, circulation and kidney during graded water immersion in humans. *J Appl Physiol* 1986; **61**:565–74
12 Park KS, Choi JK and Park YS. Cardiovascular regulation during water immersion. *Appl Human Sci* 1999; **18**:233–41
13 Weston CFM, O'Hare JP, Evans JM and Corrall RJM. Haemodynamic changes in man during immersion in water at different temperatures. *Cli Sci* 1987; **73**:613–16
14 Blyden G, Silverstein F, Epstein M, Norsk P, Brenner B, Nwadike N and Dorvil M. Lidocaine pharmokinetics during water immersion in normal humans. *J Appl Physiol* 1989; **66**:57–60
15 Epstein M, Levinson R and Loutzenhiser R. Effect of water immersion on renal hemodynamics in normal man. *J Appl Physiol* 1976; **41**:230–33
16 Balldin UI, Lundgren CEG, Lundvall J and Mellander S. Changes in the elimination of 133 Xenon from the anterior tibial muscle in man induced by immersion in water and by shifts in body position. *Aerospace Med* 1971; **42**:489–93
17 Brechat P-H, Wolf J-P, Simon-Rigaud M-L, Brechat N, Kantelip J-P, Bertherlay S and Regnard J. Influence of immersion on respiratory requirements during 30-min cycling exercise. *Eur Respir J* 1999; **13**:860–66
18 Choukran M-L, Kays C and Varene P. Effect of water temperature on pulmonary volumes in immersed human subjects. *Respir Physiol* 1989; **75**:255–66
19 Cohen R, Bell WH, Saltzmann HA and Kylstra JA. Alveola-arterial oxygen pressure differences in man immersed up to the neck in water. *J Appl Physiol* 1971; **30**:720–23
20 Lollgen H, von Nieding G, Krekeller H, Smidt U, Koppenhagen K and Frank H. Respiratory gas exchange and lung perfusion in man during and after head-out water immersion. *Undersea Biomed Res* 1976; **3**:49–56
21 Derion T, Guy HJB, Tsukimoto K, Prediletto WSR, Poole DC, Knight DR and Wagner PD. Ventilation-perfusion relationships in the lung during head-out water immersion. *J Appl Physiol* 1992; **72**:64–72
22 Choukran M-L and Varene P. Adjustments in oxygen transport during head-out immersion in water at different temperatures. *J Appl Physiol* 1990; **68**:1475–80
23 Strong LH, Gee GK, Goldman RF. Metabolic and vasomotor insulative responses occurring on immersion in cold water. *J Appl Physiol* 1985; **58**:964–77
24 Nakamitsu S, Sagawa S,Miki K, Wada F, Nagaya L, Keil C *et al.* Effect of water temperature on diuresis-natriuresis: AVP,

ANP and urodilatin during immersion in men. *J Appl Physiol* 1994; **77**:1919–25
25 Mano T. Sympathetic nerve mechanisms of human adaptation to environment – findings obtained by microneurographic studies. *Environ Med* 1990; **34**:1–35
26 Connelly TP, Sheldahl LM, Tristiani FE, Levandoski SG, Kalkhoff RK, Hoffman MD and Kalbfleisch JH. Effect of increased central blood volume with water immersion on plasma catecholamines during exercise. *J Appl Physiol* 1990; **69**:651–56
27 Norsk P, Bonde-Petersen F and Christensen NJ. Catecholamines,circulation and the kidney during water immersion in humans. *J Appl Physiol* 1990; **69**:479–84
28 O'Hare JP, Dalton N, Roland JM, Gooding J, Payne B, Walters G and Corrall RJM. Plasma catecholamine levels during water immersion in man. *Horm Metab Res* 1986; **18**:713–16
29 Pirnay F, Deroanne R and Petit JM. Influence of water temperature on thermal, circulatory and respiratory responses to muscular work. *Eur J Appl Physiol* 1977; **37**:129–36
30 Sagawa S, Shiraki K, Yousef K and Konda N. Water temperature and intensity of exercise in maintenance of thermal equilibrium. *J Appl Physiol* 1988; **65**:2413–19
31 Craig AB and Dvorak M. Thermal regulation during water immersion. *J Appl Physiol* 1966; **21**:1577–85
32 Costill DL, Cahill PJ and Eddy D. Metabolic responses to submaximal exercise in three water temperatures. *J Appl Physiol* 1967; **22**:628–32
33 Craig AB and Dvorak M. Thermal regulation of man exercising during water immersion. *J Appl Physiol* 1968; **25**:28–35
34 Tajima F, Sagawa S, Iwamoto J, Miki K, Claybough JR and Shiraki K. Renal and endocrine responses in the elderly during head-out water immersion. *Am J Physiol (Regulatory Integrative Comp.Physiol.23)* 1988; **254**:R977–R983
35 Byrne HK, Craig JN, Willmore JH. A comparison of the effects of underwater treadmill walking to dry land treadmill walking on oxygen consumption, heart rate and cardiac output. *Journal of Aquatic Physical Therapy* 1996; **4**:4–11
36 Senay LC and Pivarnik JM. Fluid shifts during exercise. *Exerc Sport Sci Rev* 1985; **13**:335–87
37 Ertl AC, Bernauer EM and Hom CA. Plasma volume shifts with immersion at rest and two exercise intensities. *Med Sci Sports Exerc* 1991; **23**:450–57
38 Morlock JF and Dressendorfer RH. Modification of a standard bicycle ergometer for underwater use. *Undersea Biomed Res* 1974; **1**:335–42
39 Shapiro Y, Avellini BA, Toner MM and Pandolf KB. Modification of the Monark bicycle ergometer for underwater exercise. *J Appl Physio: Respirat Environ Exerc Physiol* 1981; **50**:679–83
40 Kame VD and Pendergast DR. Effects of short term and prolonged immersion on the cardiovascular responses to exercise. *Aviat Space Environ Med* 1995; **66**:20–25
41 Sheldahl LM, Tristani FE, Clifford PS *et al.* Effect of head-out water immersion on cardiorespiratory responses to dynamic exercise. *J Am Coll Cardiol* 1987; **10**:1254–58
*42 Sheldahl LM, Wann LS, Clifford PS, Tristani FE, Wolf LG and Kalbfleisch JH. Effect of central hypervolaemia on cardiac performance during exercise. *J Appl Physiol* 1984; **57**:1662–67
43 Sheldahl LM, Tristani FE, Connelly TP, Levandoski SG, Skelton MM and Cowley AW. Fluid-regulating hormones during exercise when central blood volume is increased by water immersion. *Am J Physiol* 1992; **262**:R779–R785
44 McArdle WD, Magel JR, Lesmes GR and Pechar GS. Metabolic and cardiovascular adjustment to work in air and water at 18, 25, and 33°C. *J Appl Physiol* 1976; **40**:85–90
45 Moore TO, Bernhauer EM, Seto G, Park YS, Hong SK and Hayashi EM. Effects of immersion at different water temperatures on graded exercise performance in man. *Aerospace Med* 1970; **41**:1404–08
46 Miwa C, Sugiyama Y, Mano T, Matsukawa T, Iwase S, Watanabe T, Kobayashi. Effects of aging on cardiovascular responses to gravity-related fluid shifts in humans. *J Gerontol A Biol Sci Med Sci* 2000; **55**:M329–35
47 Miwa C, Mano T, Iwase S, Matsukawa T, Sugiyama Y and Koga K. Aging reduces sympathosupressive response to head-out water immersion in humans. *Acta Physiol Scand* 1996; **158**:15–20
48 Takeshima N, Nakata M, Kobayashi F, Tanaka K and Pollock ML. Oxygen uptake and heart rate differences between walking on land and in water in the elderly. *Journal of Aging and Physical Activity* 1997; **5**:126–34
49 Evans BW, Cureton KJ and Purvis JW. Metabolic and circulatory responses to walking and jogging in water. *Res Q* 1978; **49**:442–49
*50 Town GP and Bradley SS. Maximal metabolic responses of deep and shallow water running in trained runners. *Med Sci Sports Exerc* 1991; **23**:238–41
51 Whitley JD and Schoene LL. Comparison of heart rate responses: water walking versus treadmill walking. *Phys Ther* 1987; **67**:1501–04
52 Yu E, Kitagawa K, Mutoh Y and Miyashita M. Cardiorespiratory responses to walking in water. *Med Sport Sci* 1994; **39**:35–41
53 Cureton KJ. Physiologic responses to water exercise. In: Ruoti RG, Morris DM and Cole AJ (eds) *Aquatic Rehabilitation.* New York: Lippincott, 1997:39–56
54 Nakazawa K, Yano H and Miyashita M. Ground reaction forces during walking in water. *Med Sport Sci* 1994; **39**:28–34
*55 Gleim GW and Nicholas JA. Metabolic costs and heart rate responses to treadmill walking in water at different depths and temperatures. *Am J Sports Med* 1989; **17**:248–52
56 Bishop PA, Frazier S, Smith J and Jacobs D. Physiologic responses to treadmill and water running. *Physician Sportsmedicine* 1989; **17**:87–94
57 Napoletan JC and Hicks RW. The metabolic effects of underwater treadmill exercise at two depths. *APTR* 1995; **3**:9–14
58 Hall J, Macdonald IA, Maddison PJ and O'Hare JP. Cardiorespiratory responses to underwater treadmill walking in healthy females. *Eur J Appl Physiol* 1998; **77**:278–84
*59 Moening D, Scheidt A, Shepardson L and Davies GJ. Biomechanical comparison of water running and treadmill running. *Isokinetics and Exercise Science* 1993; **3**:207–15
60 Butts NK, Tucker M and Smith R. Maximal responses to treadmill and deep water running in high school female cross country runners. *Res Q Exerc Sport* 1991; **62**:236–39
61 Butts NK, Tucker M and Greening C. Physiologic responses to maximal treadmill and deep water running in men and women. *Am J Sports Med* 1991; **9**:612–14
62 DeMaere JM and Ruby BC. Effects of deep water and treadmill running on oxygen uptake and energy expenditure in seasonally trained cross country runners. *J Sports Med Phys Fitness* 1997; **37**:175–81
63 Dowzer CN and Reilly T. Deep-water running. *Sports Exercise and Injury* 1998; **4**:56–61
64 Frangolias DD and Rhodes EC. Maximal and ventilatory threshold responses to treadmill and water immersion running. *Med Sci Sports Exerc* 1995; **27**:1007–13

65 Gehring MM, Keller BA and Brehm BA. Water running with and without a flotation vest in competitive and recreational runners. *Med Sci Sports Exerc* 1997; **29:**1374–78

*66 Svedenhag J and Seger J. Running on land and in water: comparative exercise physiology. *Med Sci Sports Exerc* 1992; **24:**1155–60

67 Yamaji K, Greenley M, Northey DR and Hughson RL. Oxygen uptake and heart rate responses to treadmill and water running. *Can J Spt Sci* 1990; **15:**96–98

68 Prins J and Cutner D. Aquatic therapy in the rehabilitation of athletic injuries. *Clin Sports Med* 1999; **18:**447–61

69 Brown SP, Chitwood LF, Beason KR and McLemore DR. Deep water running physiologic responses: gender differences at treadmill-matched walking/running cadences. *J Strength and Cond Res* 1997; **11:**107–14

70 Glass B, Wilson D, Blessing D and Miller E. A physiological comparison of suspended deep water running to hard surface running. *J Strength and Cond Res* 1995; **9:**17–21

71 Green JH, Cable NT and Elms N. Heart rate and oxygen consumption during walking on land and in deep water. *J Sports Med Phys Fitness* 1990; **30:**49–52

72 Michaud TJ, Rodriguez-Zayas J, Andres FF, Flynn MG and Lambert CP. Comparative exercise responses of deep-water and treadmill running. *J Strength and Cond Res* 1995; **9:**104–09

73 Nakanishi Y, Kimura T and Yokoo Y. Maximal physiological responses to deep water running at thermoneutral temperature. *Appl Human Sci* 1999; **18:**31–35

74 Dowzer CN, Reilly T and Cable NT. Effects of deep and shallow water running on spinal shrinkage. *Brit J Sports Med* 1998; **32:**44–48

*75 Frangolias DD, Rhodes EC and Taunton JE. The effect of familiarity with deep water running on maximal oxygen consumption. *J Strength and Cond Res* 1996; **10:**215–19

76 Michaud TJ, Brennan DK, Wilder RP and Sherman NW. Aquarunning and gains in cardiorespiratory fitness. *J Strength and Cond Res* 1995; **9:**78–84

77 Ritchie SE and Hopkins WG. The intensity of exercise in deep-water running. *Int J Sports Med* 1991; **12:**27–29

78 Brown SP, Jordan JC, Chitwood LF, Beason KR, Alvarez JG and Honea KP. Relationship of heart rate and oxygen uptake kinetics during deep water running in the adult population – ages 50 to 70 years. *Journal of Aging and Physical Activity* 1998; **6:**248–55

79 Wilder RP, Brennan D and Schotte DE. A standard measure for exercise prescription for aquarunning. *Am J Sports Med* 1993; **21:**45–48

80 Schiffer J. Aquajogging. *New Studies in Athletics* 1997; **12:**121–39

J. Hall (corresponding author), Physiotherapy Department, Royal United Hospital, Coombe Park, Bath, BA1 3NG, UK. Tel: 01225 824292; Fax: 01225 825978; Email: jhall-work@yahoo.co.uk

D. Blake, Royal National Hospital for Rheumatic Diseases, Upper Borough Walls, Bath, BA1 1RL, UK

G. Garbutt, School of Health Sciences, University of East London, East London, E15 4LZ, UK